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7/25/68

A QUANTITATIVE EVALUATION OF CONSTRUCTION FEATURES FOR INDUSTRIAL BUILDINGS

A THESIS

Presented to

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by

Franklin Camp Bacon

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A QUANTITATIVE EVALUATION OF CONSTRUCTION

FEATURES FOR INDUSTRIAL BUILDINGS

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SUMMARY

Heretofore there has not been available to managerial, architectural and engineering personnel a convenient methodology to facilitate decisions regarding the construction features for proposed industrial enclosures. Required was (1) the compilation of current industrial building technology and (2) the development of a comprehensive procedure for considering the numerous technically feasible alternatives. The information for this thesis was derived from both current literature and interviews with persons professionally involved in the technology of industrial buildings. Through such interviews, it was concluded that the plant manager who was aware of the cost of building maintenance (or in other words, the economic consequence of initial building design decisions) was the exception. This fact emphasizes the potential benefit of an evaluation procedure founded on an economic criterion.

This thesis proposes a methodology for evaluating the design of industrial buildings on an economic criterion of which the initial cost and the operating costs are primary elements. The practicality of the procedure is demonstrated in an example. The application of the procedure is not seriously jeopardized by economic vacillations (i.e. inflation, recession, tax laws, etc.), although changes in construction technology which alter the cost relationships between materials and labor require re-evaluation of the affected areas of the procedure.

CHAPTER I

INTRODUCTION

Objective

The objective of this thesis is the development of a procedure for evaluating and minimizing the costs of constructing and operating an industrial building. All the costs associated with industrial buildings will be categorized as either construction (initial investment) costs or as operating costs. These costs can normally be considered as being inversely proportional one to the other; hence, to minimize the sum of these two costs will require a trade-off procedure which will accurately evaluate the alternatives on the basis of economy.

This thesis entails (1) an evaluation of the alternative construction features of industrial buildings, their suitability to particular applications and their costs; (2) an evaluation of the operating costs associated with various construction features and their operating environments; and (3) a procedure for determining the building features which (providing for the construction and operating costs specifications of the building) represent the minimum total of investment and operating costs.

Purpose

The purpose of this thesis is to provide a guide for evaluating alternative design features of industrial buildings in order to provide for minimum construction and operating costs. It is intended that users of this procedure will be those in a plant engineering activity whose responsibilities include the determination of building design specifications for release to contractual bidders, and for cost estimating for management approval. The guide may also serve the plant engineer by providing a rigorous definition of the operating costs of existing buildings and help to reduce the operating costs of these buildings.

Scope and Limitations

The subject of industrial buildings incorporates a diverse range of structural forms, materials and costs. In the discussion of costs, particularly operating costs (i.e. insurance, maintenance, environment control, etc.) the scope of this thesis considers all the noteworthy costs and their relationship to the building and its intended application. Structural types are limited to the more standard forms, as will be the construction materials. The applications and operating environments of the building are classified in several classes, each defined as it affects the operating costs of the building.

The procedure developed to consider all the cost related aspects of the building in the determination of design specifications concentrates primarily on a minimum cost (of construction and operation) building. The aesthetic aspects of the building are dealt with superficially and with no attempt at an economic evaluation.

Procedure

The term "industrial building" applies to a wide variation of structural types, construction materials, and site requirements, all of which affect the construction costs, as well as the operating costs of the building. To simplify the analysis of the general cost functions, a standard rectangular building configuration is used to develop the relationships of the cost functions as they are affected by the construction type and the construction materials.

Having defined the cost relationships of the various physical aspects of the building, a procedure for selection of feasible design specifications appropriate to the operating and investment requirements is described. The selection procedure incorporates consideration of environmental conditions (internal and external to the building) as well as area and cube requirements. This procedure is then combined with the analysis of cost relationships to develop a method for quantitatively evaluating the applicable construction features of the proposed building. The quantitative evaluation is accomplished in terms of dollar ratios and will be described generally by the simple objective function:

$$C_t = C_c + C_o$$

where

C_t = Total cost

C_c = Construction cost

C_o = Operating costs

The requirements, of course, are to minimize C_t subject to such constraints as maximum desired initial investment, maximum acceptable insurance costs or maintenance costs. Such constraints would be defined by management decisions reflecting management experience and/or desires.

Literature Survey and Background

The construction of an industrial building represents an investment which continues for the life of the building. This investment is composed of two functions:

1. The initial investment in the construction of the building.
2. The cost-of-use of the building.

The combined investment might be mathematically represented as

$$C_t = C_i + \sum_{t=0}^{k} C_o = \text{Total Investment}$$

C_i = Initial Investment Cost

(which includes the cost of materials and labor)

C_o = Operating Costs

(which are the costs incurred as a result of a design decision concerning the type of material of construction),

and where k = the life of the building in years.

Hence the initial construction investment is considered as a singular investment while the cost-of-use is a continuing investment occurring over the life of the building, perhaps recognized as an annual cost of (building) operation. As noted, the operating costs (or cost-of-use) are related to design decisions concerning the initial investment. As an example, the choice of one particular type of building and material of construction will engender maintenance, heating, and insurance costs which would be difference for some other building type or construction material.

The concept of evaluating the design of industrial buildings by comparing the investment cost of the building components and their respective repetitive operating costs (i.e. maintenance, insurance, etc.) has been previously suggested. The concept of the lowest initial investment not necessarily being the most economical investment is common in any consumer oriented endeavor where cost and value are directly proportional. In much of the previous literature concerning the design or selection of basic design components for industrial buildings, the concept is mentioned only briefly, and then merely as an admonition to exercise caution in selecting building components. It has not been developed as a useful tool. Dr. P. A. Stone, in Building Design Evaluation, recognizes that "often the running costs of a building are three times as great as the first costs," and presents some well established techniques for evaluating the "running" or operating costs as consequences of design decisions. What is lacking is a practical procedure which attempts to define the various operating costs and their relationship to current building components as a "work-a-day" method of evaluation. Possibly what has discouraged the development of such a procedure is the continual change taking place through inflation and the technology of structures and materials, which could cause any such procedure to have only a transient value. However, if a procedure were developed under the constraints of current technology and monetary values, it might serve (1) as a useful tool for the present and (2) as a foundation upon which the necessary additions, deletions, and corrections could be made to keep the procedure up to date. This, then, is the intent of this thesis.

CHAPTER II

MANAGEMENT DECISIONS IN THE DESIGN OF INDUSTRIAL BUILDINGS

Although the primary function of an industrial building is to provide an efficient enclosure for production, the building also functions as a place of employment for the employees, as an image of the enterprise to its customers, and as a manifestation of the corporation's view of itself. The accomplishment of the first function is the responsibility of the engineering staff, while the effectiveness of the latter three is dependent upon management policies. Since, in the selection of building systems there is a considerable range of possible initial investments (the subject of this thesis), management policies must provide a guide to the building designers as to the importance management attaches to the appearance of its buildings to the worker, to the consuming public, and to itself. The concept of an industrial building as a corporate image is growing in acceptance, bearing heavily upon management's role in the design process. Hence, a brief discussion of the pertinence of management originated decisions on this subject prefaces the body of this thesis.

As a Place to Work

Aside from providing the basic amenities for the physical comfort of the employees working in the plant, the managements of many large firms are finding it productive to provide also for their mental attitude as well. It is, after all, the employee's attitude which determines the effort he will put forth toward meeting standards of quality and productivity. The employee's attitude can be "conditioned" by providing an environment projecting the characteristics expected in his performance and appealing to his sense of pride to produce at this level. Johnson and Johnson, for example, require cleanliness and quality in their medical products, which in turn requires the cooperation of the employees. To aid in accomplishing this, Johnson and Johnson insures that the employee sees quality and cleanliness in the construction of the building. The buildings appear clean and sturdy in construction, so that the employee associates these characteristics with the performance expected of him. Aware of these desirable characteristics, the employee also attaches a certain degree of pride to his association with the enterprise, an attitude which is also reflected in his performance.

As a Corporate Image to the Consumer

Regardless of the level of consumption (household, professional, business, or industrial), if the buildings of the enterprise are available for view by the consumer, the appearance of the buildings will have an effect upon the consumer's opinion of the products. Johnson and Johnson sells through doctors, hospitals, medical associations, and medical wholesale outlets. In offering guided tours of their facilities the consumer is impressed with the reliable sanitation of the process. This characteristic is further reinforced in the design, materials, and construction techniques of the building, as well as with the process. The Coca-Cola Company also maintains minimum acceptable specifications for the buildings erected by their franchised bottlers. To insure that their bottling plants project quality, wholesomeness, and cleanliness, Coca-Cola requires a minimum cost of approximately $8.00 per square foot for the buildings alone.[1] Hence the image the enterprise wishes to project to its customers can be evidenced in its plant and office buildings.

As a Manifestation of the Corporate Self-View

Corporations, like people, have personalities. Corporate personalities are formed by management policies and are only fully understood and appreciated from within the enterprise. As a segment of this personality, enterprises exhibit some level of pride with themselves and their success, which is in part reflected in some minimum acceptable standards of quality in plant and office buildings. These standards are either explicitly outlined in management policy or are implied from the enterprise's history of conduct and construction. The quality acceptable to the enterprise is a measure of the corporation's estimation of its success, its awareness of quality, and its striving for improved quality.

Development of a Building Design Policy

If a design policy should be assessed by management as having productive potential, a management group should be designated to confer with the responsible engineer and architect (the technical group) to develop a plant (and office) building design policy. The development of such a policy might be similar to the following:

1. The views, proposed ideas, and the range of acceptable

costs, as well as the image, promulgated by higher management should be presented to the policy development group.

2. The policy group should discuss with the architect and engineer the images to be projected by the buildings (i.e. stability, quality, utility, luxury, progressive, conservative, cleanliness, price, comfort, success, etc.).

3. The technical group should produce suggestions for accomplishing the image required by management. The suggestions might take the form of building types, construction materials, construction techniques, landscaping, the use of trademarks, symbols, and color. Several preliminary designs should be prepared by the technical group and presented with estimated costs to the policy group. The policy group should then discuss the merits and disadvantages of the various proposed designs, selecting a representative sample of alternative designs.

4. The representative designs should then be presented to higher management for approval of their preferences in building designs and their recommendations.

5. Having obtained approval for specific design types and costs, the formal policy can be drafted by the policy group, and re-submitted to higher management for their final approval.

The above suggested procedure is, of course, for a large corporation in which management and technical groups have widely separate areas of responsibility. But the small industrial enterprise, or the small owner-operator commercial enterprise, considering new buildings, would benefit from a carefully developed (if somewhat less formal) building design policy.

CHAPTER III

ANALYSIS OF CONSTRUCTION COSTS

In 1967, over $3.5 billion was allocated by private industry for industrial buildings, representing better than 20% of the total expenditures for industrial expansion.[2] It is usually the intent of industry to erect the least expensive building which will satisfy their operating and aesthetic requirements. But the lowest initial cost building is not necessarily the most economical in the long run, for the cheaper materials and construction methods often result in higher operating costs and shorter working life than do the more expensive alternatives.

This section presents an analysis of the cost of constructing an industrial building. The costs presented include materials and labor for fabrication and erection of the basic components of an industrial building:

1. Foundations
2. Floors
3. Structural Framing (roof support and columns)
4. Walls and Interior Partitions
5. Roofs
6. Environmental Control Equipment

Since several of a buildings component costs (for walls, foundations, and structural framings) are effected by the general shape of the building, the cost functions for industrial buildings will be analyzed in relation to standard building configurations: square and/or rectangular. Figure 1 illustrates profiles of typical standard building components to be considered in the design of a building. (The illustrated components include (1) the truss frame, (2) the open web joist, (3) and the rigid frame; which represent the mainstay of industrial building construction at this date.)

Figure 2 illustrates the trend of component cost emphasis as the number of employees (and the level of their skills) increase. With the increase in employment (or level of skill) the share of employee oriented components (i.e. heating, air conditioning, kitchens, parking lots, etc.) increases in proportion to the more basic components (i.e. roof, frame, etc.). The actual expenditures for employee oriented components increases significantly compared to expenditures for the basic components (i.e. for 25 employees and 1000 employees, respectively, roof costs are $1.23 and $1.50, while heating and air conditioning are $0.74 and $5.65). The buildings in this comparison are single story, 200,000 square feet steel frame buildings enclosing metal fabricating enterprises: a house trailer assembler employing 25 persons, a pre-engineered building fabricator employing 600 persons, and an air frame fabricator and assembler employing 1000 persons.

The effect of a building's length-to-width ratio upon the cost of the building is illustrated in Figure 3, for which the floor area is unchanged but the length of the perimeter increases as the deviation of the building shape changes from a square to a rectangular

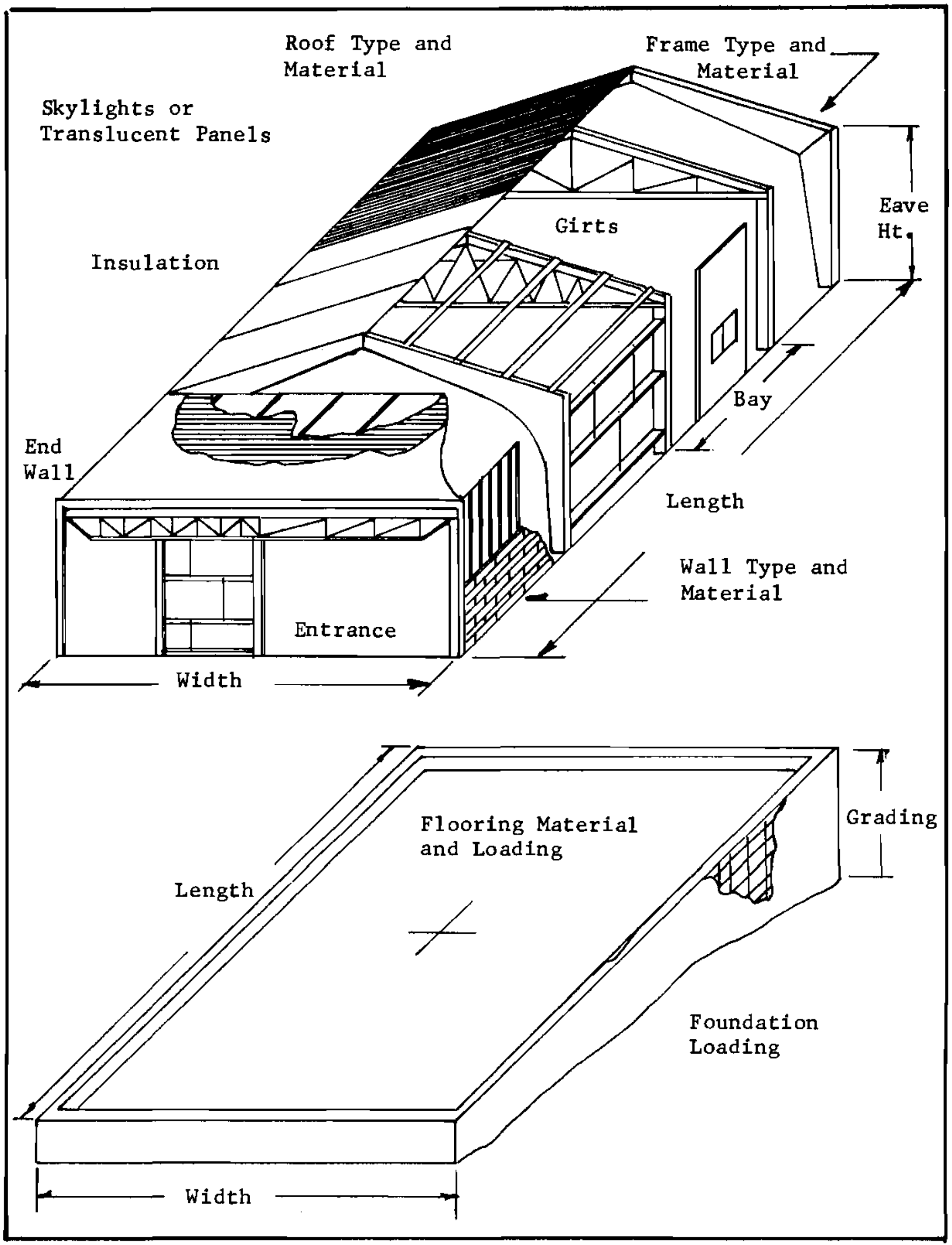


Figure 1. Typical Profiles of Standard Industrial Buildings

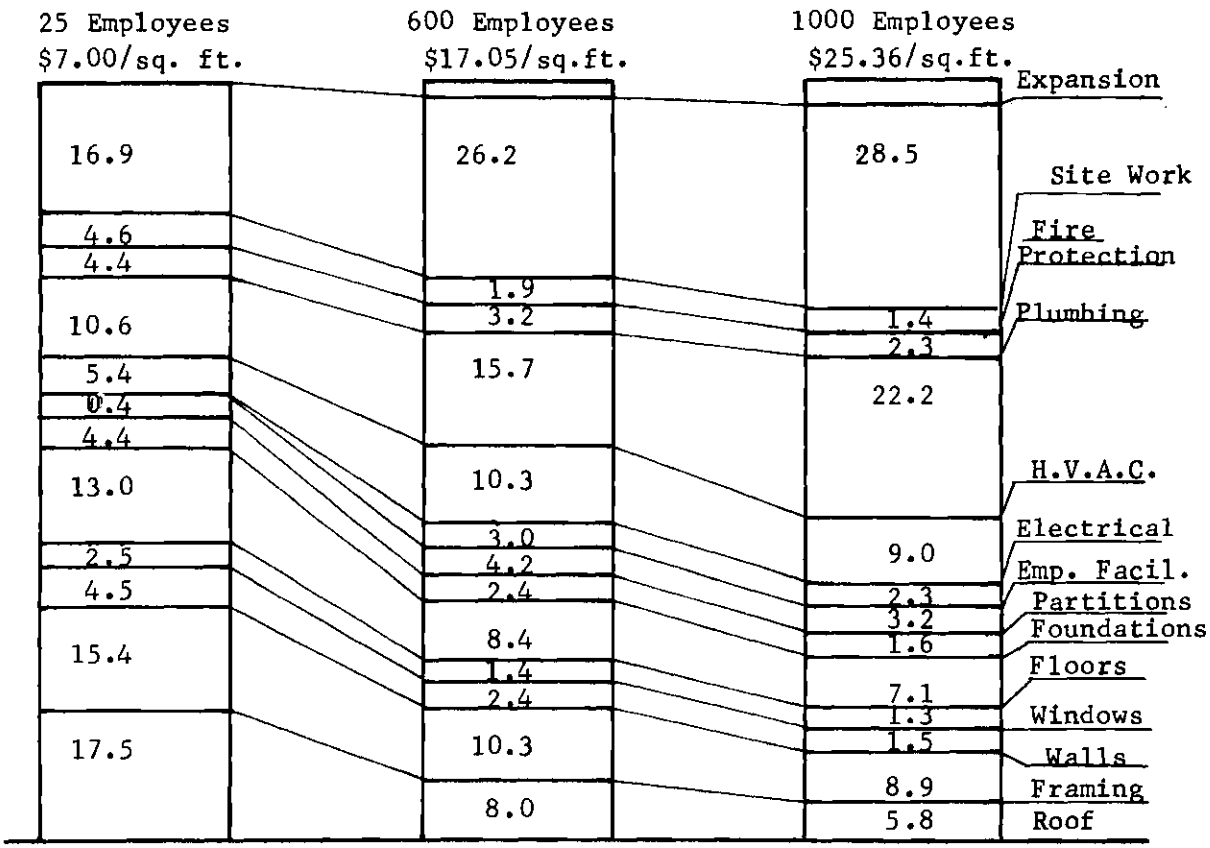


Figure 2. Breakdown of Industrial Building Costs[3]

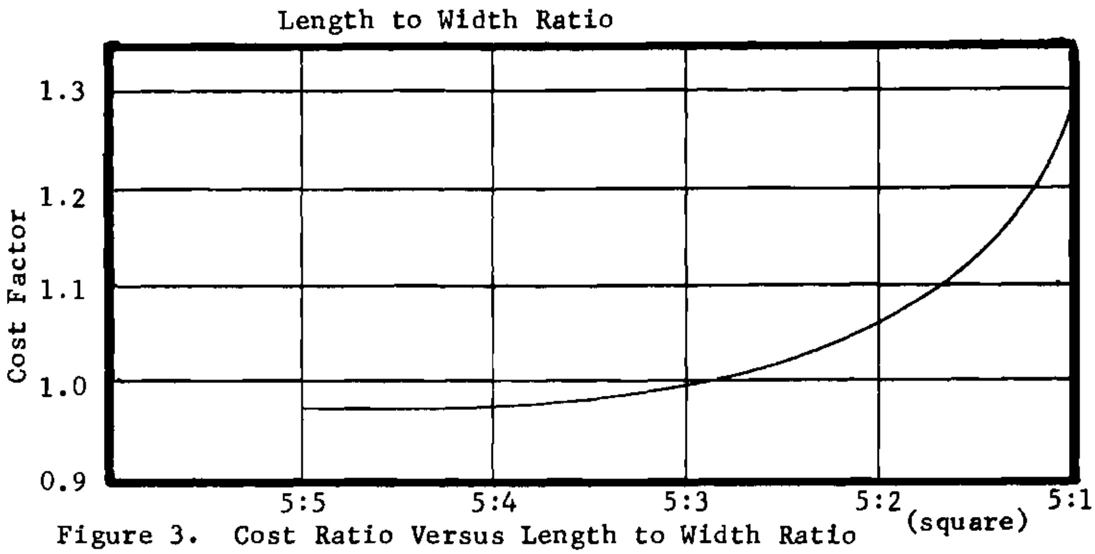


Figure 3. Cost Ratio Versus Length to Width Ratio

configuration. Figure 3 can be used to determine the cost multipliers for foundations and walls.

Foundations

The cost of a foundation for an industrial building depends upon several factors, notably:

1. The load bearing capacity of the soil
2. The terrain upon which the foundations are to be placed
3. The number of columns (which is mainly a function of the layout of process and material flow
4. The loading of the columns
5. The shape of the building perimeter

Foundations are normally related to the site cost, since cost is so much a function of the soil conditions. Foundations for industrial buildings are of two types: (1) the foundations walls around the perimeter of the building and (2) the footings upon which building columns bear.

The design load of the footings should incorporate the probability of additional floors or suspended equipment. The cost of footings increases almost directly with the load of the building. The load bearing capacity of the soil has the opposite effect. As the soil load bearing capacity increases, the cost of the footings decreases. But more often than not the soil bearing capacity is not significantly alterable by the contractor or owner, since it is a characteristic of the local geography. In extreme cases the use of piling can provide adequate bearing, but at a substantial increase in cost. The terrain upon which the building is to be erected is also important, as the grade walls (costing approximately $60 per cubic yard in 1968) must adjust the terrain variations to the predetermined grade. Future horizontal expansion of the building in the direction of a slope can be considerably reduced if the land is graded level, thus reducing the height of the walls required to maintain grade.

In estimating concrete costs, the terminology is the cost per cubic yard with the cost varying in relation to:

1. The complexity of forms
2. The content of steel reinforcing
3. The finishing costs
4. The placing costs
5. The type of contact faces on the forms
6. The size of the "pour"
7. The component "mix" of the ingredients in concrete

As the building configuration deviates from a square, the cost of the foundation walls increases because the perimeter of the building increases more rapidly than the area. Figure 4 illustrates the cost ratio trend as affected by the deviation from the square. As the area of the building increases (within a given shape), the cost per square foot for the foundation walls decreases. If a column is required for span support the cost of footings would be approximately $40 per cubic yard (with normal footings requiring up to 0.75 cubic yards (or costing approximately $30) this would be about three cents per square foot for one column every one thousand square feet.

Floors

The floor of an industrial building is the foundation for much of the materials handling and process equipment, and serves as a thoroughfare for personnel and materials movement. As such it is perhaps the most sensitive of the building components to the processes of production and the least flexible and most expensive component to repair or alter. Hence, due consideration should be given to the selection and installation of the proper flooring.

The concrete ground slab is increasingly becoming the standard industrial floor or sub-floor for other flooring surfaces. The ground slab should be adequately sealed from the ground to prevent hydrostatic seepage through the slab. This can be accomplished by either laying a preliminary "roof" slab on the ground which is allowed to cure before the primary slab is poured on top or by any of the numerous additives available in the concrete to prevent seepage. Floor sur-

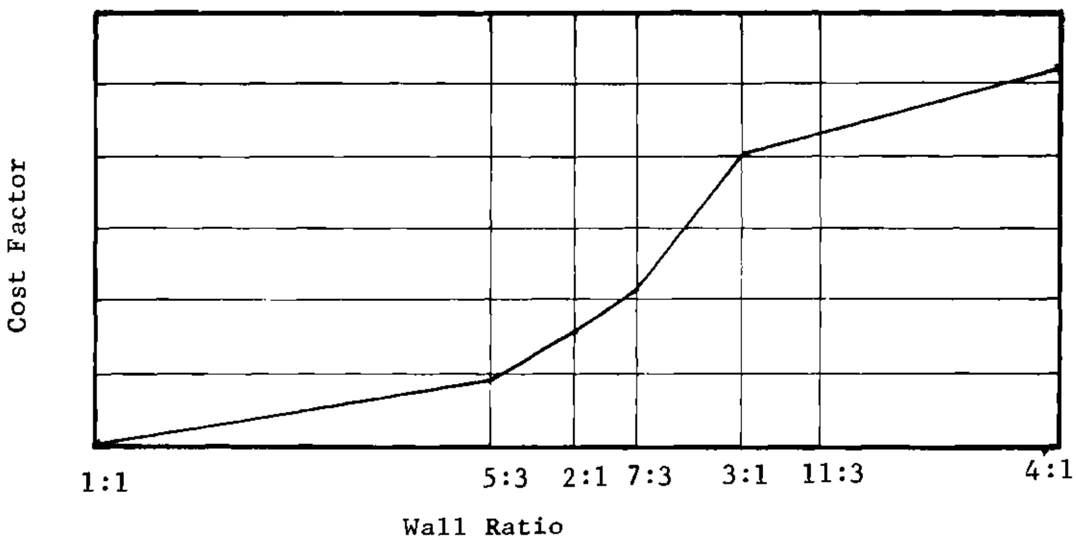


Figure 4. Cost Trend for Deviation from Square Foundations

faces subject to process or wash down liquids should be properly sloped for drainage and have rough "broom" finishes to improve the traction of foot and wheeled traffic when the floors are wet from washing and spillage.

Floor surfaces for sanitary or highly corrosive services should be impervious to standing process liquids, especially certain reactive liquids, which could cause swelling of the ground under the slab and possible buckling of the slab. Many seemingly harmless process materials can cause extensive damage to some flooring materials. For instance, sugar is very reactive with concrete floors, capable of leaching the lime from the concrete. Hence, when not entirely knowledgeable about process materials and construction materials, it is wise to consult a reference or building contractor familiar with such problems. The selection of a floor surface should consider every eventuality in a process from corrosion and heavy mechanical traffic to foot comfort and sanitation. Table 1 lists the predominant industrial flooring surfaces, their approximate cost per square foot, and their normal applications. All costs noted in this paper are as of the spring of 1969.

Structural Framing

To provide greater flexibility of operation and expansion, present day industrial buildings seldom use load bearing walls, but rely upon the structural framing for the support of the roof and other integral loads such as wall panels, lighting, ventilation, process, and materials handling equipment.[4] The primary types

Table 1. Flooring Systems[5]

Flooring Surface	Application	Characteristics	Cost Per Sq. Ft.	Cost Index*
Concrete Ground Slab	Medium to heavy traffic, resistant to mineral oils, alkalis, organic solvents.	Poor standing comfort, not resistant to acids, vegetable oils and animal fat, will dust and spark. 3000 PSI compressive strength.		
3"			$0.25	0.75
4"			$0.33	1.00
5"			$0.42	1.28
Concrete Surface Preparations				
Asphalt Tile	Good wet traction, water resistant, subject to chemical attack by acids and caustic.	Good standing comfort, medium to heavy traffic, non-spark, non-dust, resilient.	$0.80	2.42
Asphalt Plank			$0.75	2.38
Synthetic Rubber	Resistant to acids and alkali, poor wet traction.		$0.60-$0.80	
Epoxy Surfaces	Chemical resistant, wears and indents, 140°F limit.	Poor wet traction and standing comfort.	$0.50	
Hardeners (in 4" slab w/trap rock)	Heavy duty, abrasion, steel wheeled traffic.		$0.75	2.38
Emery Rock and as above				
Tiles	Resistant to chemical attack, wear, sparking, dusting, sanitary. Low mechanical strength under impact.	Ease of sanitary maintenance.		
Quarry			$1.40	4.25
Corning				
Brick			$1.04-$2.35	
Creosoted Wood Block (Maple)	Light to heavy traffic, absorbs oil and noise, good standing comfort, fair traction.	Damaged by standing liquids, difficult to clean. Non-spark non-dust. W/concrete sub-base and asphalt adhesive.		
2"			$1.20	3.64
3"			$1.40	4.25

*Including 3" concrete ground slab

of structural framing are:

1. The rigid frame
2. The truss frame
3. The post and beam

The rigid frame, truss frame and post and beam frame are available in either pre-engineered or in fabricated-to-order spans and capacities. The pre-engineered frames can be procured only in standard weights and spans, but are less expensive and offer quicker deliveries than do the fabricated-to-order styles. The pre-engineered frames are often limited in load carrying capabilities and are not as adaptable to modification for expansion or process change as are the fabricated frames. The materials of construction for structural framing members (roof support and columns) include mild steel, wood, concrete, aluminum, and combinations of these. Each combination of structural framing and materials is suitable for some range of specifications reflecting the required performance and cost parameters. Following are brief discussions of the advantages and disadvantages of the above types of structural framing and materials.

Figures 5, 6 and 7 illustrate the typical construction features of (1) the rigid frame building, (2) the truss frame building, and (3) the post and beam frame building. Table 2 summarizes the three standard frames for industrial buildings.

The <u>rigid frame structure</u> is a relatively lightweight, simplified continuous frame system incorporating a single member span. These frames are often prefabricated of specially fabricated (as opposed to extruded and rolled steel forms) steel members, wood, or concrete, and can be

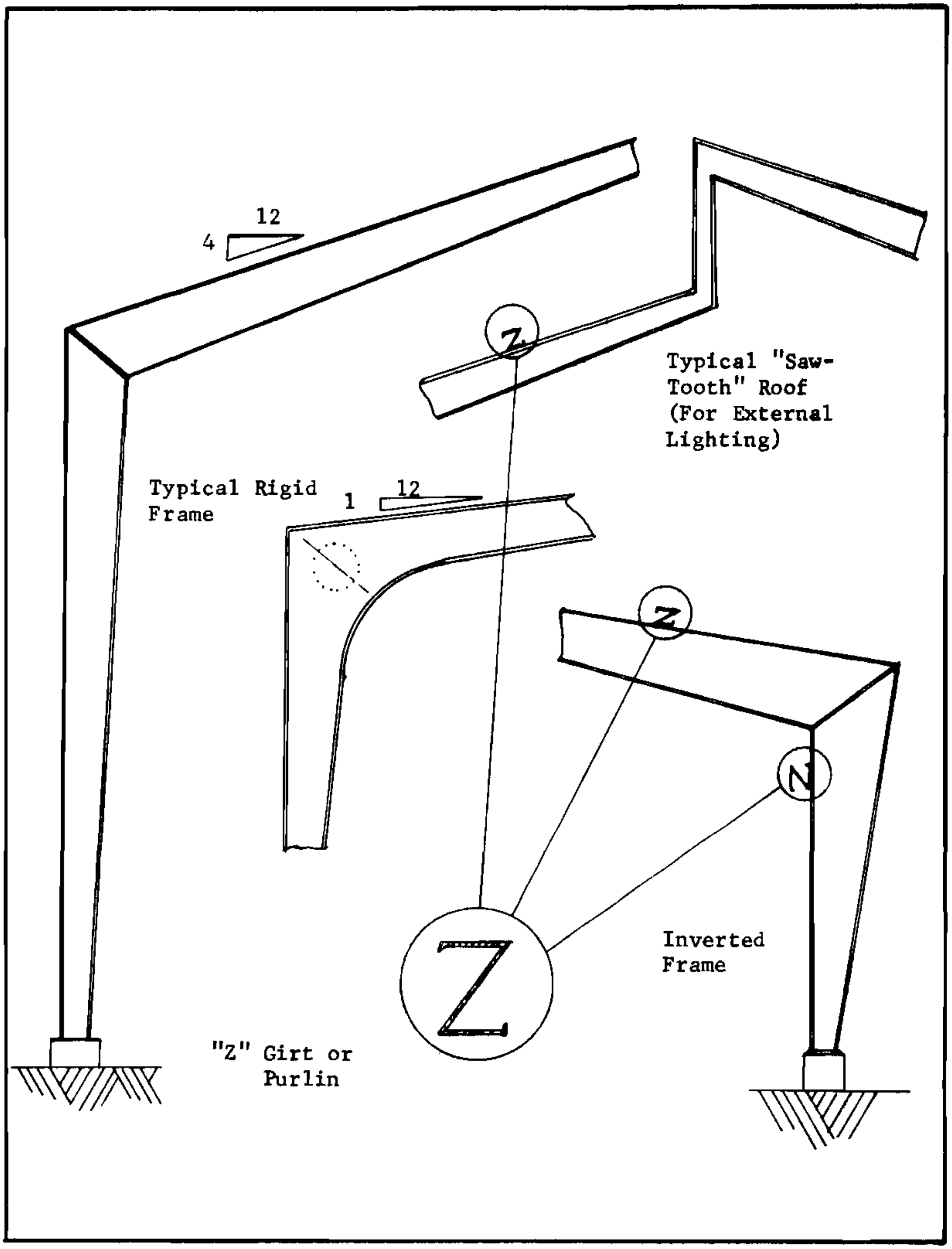


Figure 5. Typical Structural Members for Pre-Engineered Buildings

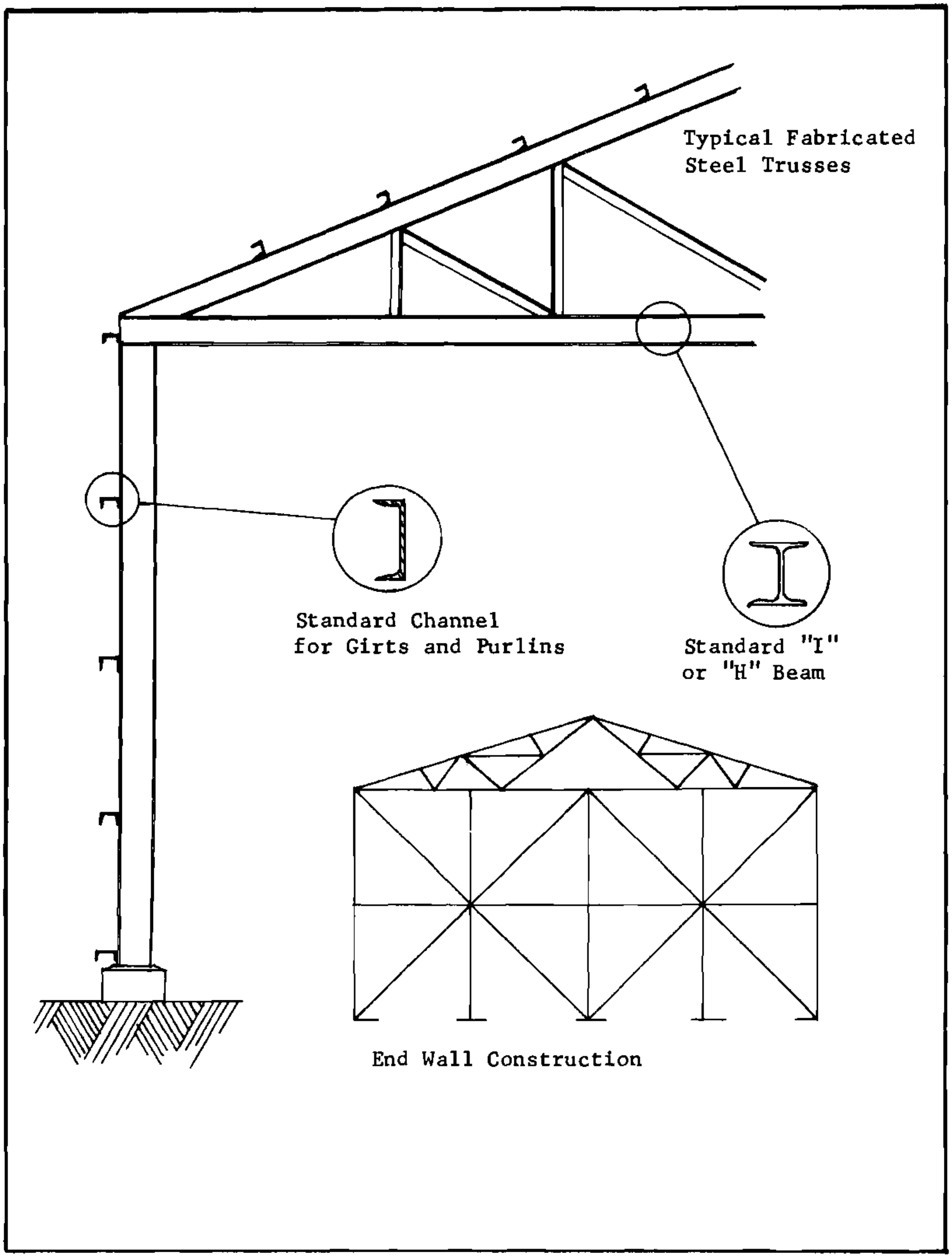


Figure 6. Typical Structural Members for Fabricated Buildings

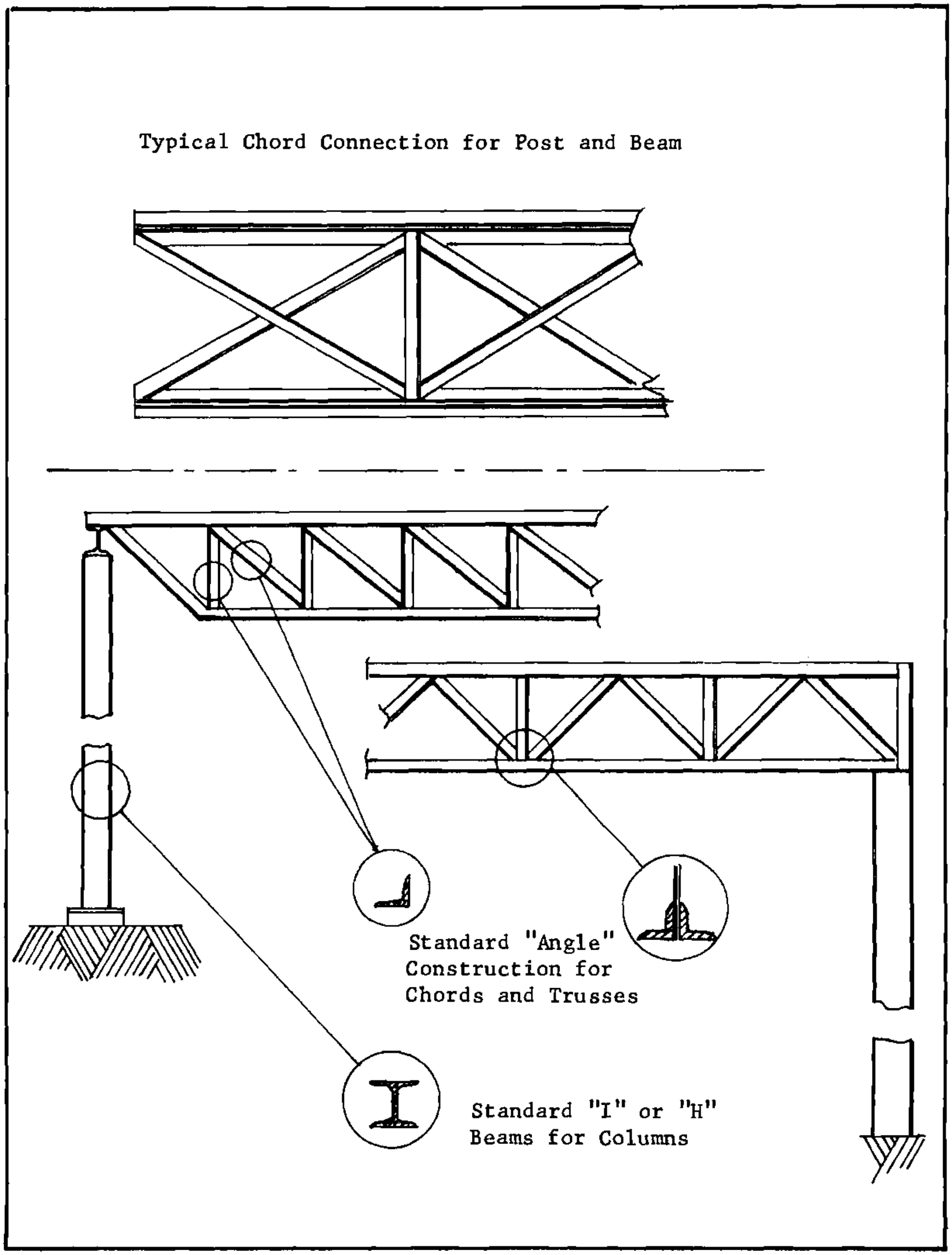


Figure 7. Typical Structural Members for Post and Beam Frame Buildings

Table 2. Summary of Structural Framing[6]

Type of Structural Framing	Comments on Application
Truss Frame	Available in fabricated form from 20 to 150 feet in span, bay length open, eave height open, load support open, clear height to eave, sloped roof, flexible for modification, column placing to suit.
Rigid Frame	Available in pre-engineered form, highly standardized (i.e. 24 foot long bay, 16 foot eave, 40,50,60,70 80, 100, and 120 foot spans), average cost increase over standard: 20 foot eave - 3.4% 20 foot long bay - 5.5% 24 foot eave - 7.0% 18 foot long bay - 11.0% Limited loading of frame, clear height to roof, sloped roof (some low sloped roofs can use built-up system), quick delivery, inflexible for modification, ease of horizontal expansion. 5 ton maximum load on frame, 10 tons with modification. Some building codes restrict rigid frame construction.
Post and Beam	Available in standard pre-engineered forms, standard bay from 20 x 30 to 50 x 50, limited loading of joist, flat roof, built-up roof, clear height to eave, quick delivery.

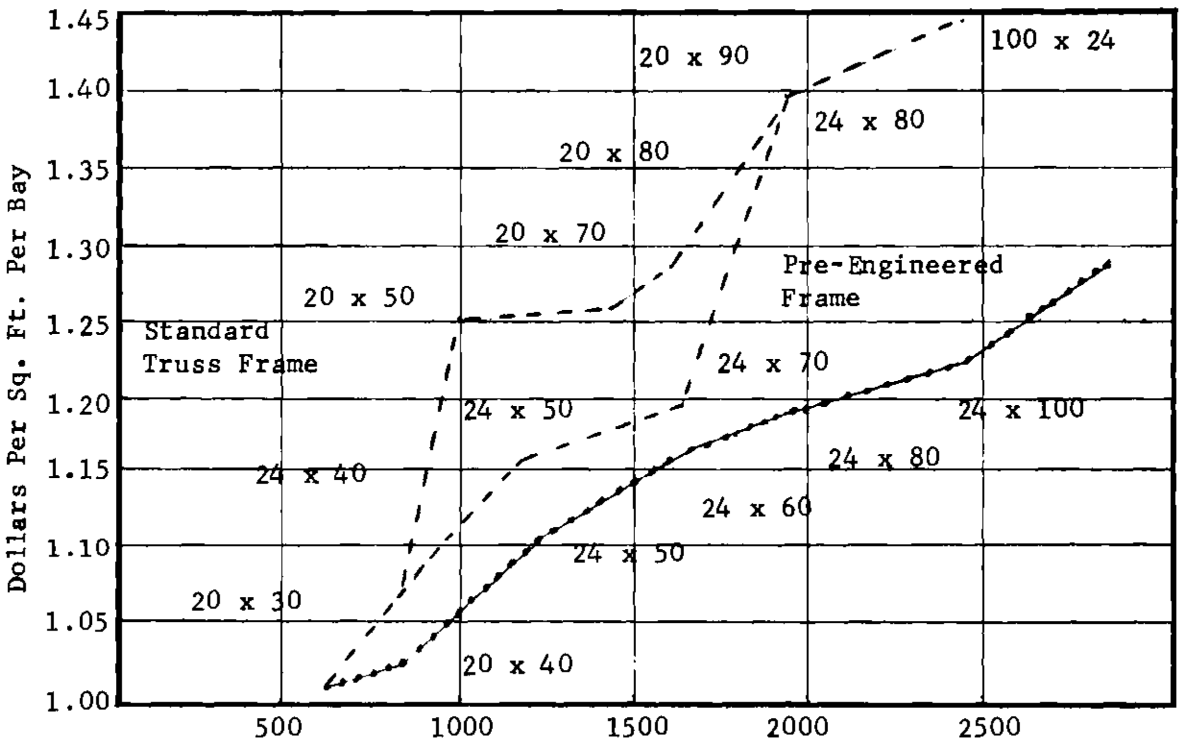
erected at the building site using only a crane and wrenches. The advantages of the rigid frame are the lower cost of construction, the additional clear height under the roof, and the lower maintenance cost because of the smaller surface area requiring painting. The limitation of the load carrying capacity of the rigid frame (five tons normally, ten tons with substantial redesign and modification) reduces the usefulness of the frame for supporting process and materials handling equipment and precludes expansion to a second story, although a mezzanine can be added if the eave height is sufficient.

The truss frame structure is fabricated of standard extruded and rolled steel members or wood beams, using the multiple trusses to provide rigidity and strength. The truss systems are normally fabricated at a shop and erected in the field using either bolted or welded construction. The advantages of the truss frame are its load carrying capacity for supporting process and materials handling equipment and its flexibility of member modification for horizontal and vertical expansion. With reasonable care the members can be modified to suit changes in load and clearance requirements. The drawbacks of these truss systems are the increased cost and time of fabrication, erection and maintenance, and the limited use of the cube above the bottom chords of the system. Truss systems are most commonly used for buildings requiring load bearing structures with the capability for modification and expansion in several directions to meet changes in the process.

The post and beam frame with standard extruded steel columns (wide flange or pipe columns) provide a flat roof of light to heavy bearing capacity. The post and beam frames provide for passage of of piping, ducting, and electrical conduit, while allowing for a "flat" insulated roof of gypsum, steel, concrete or wood with a built-up covering of tar (or asphalt), felt and gravel. The joists are normally purchased according to length of span and load required, and are delivered ready for mounting to the perimeter horizontal members supported by the columns. Open web joists are also available in double sloping roof for extremely light loads such as farm buildings and simple equipment enclosures. The advantages of the open web joists are the reduced time and cost of procurement, erection and possible improvements in heating and/or cooling economy. The disadvantages are the lower load bearing capacity for suspended loads and the reduction in available cube above joist chords. Applications of the open web joist construction include (1) office space (2) industrial activities requiring a minimum of overhead loading or (3) having a worker density requiring heating and cooling, and (4) warehousing.

Figure 8 illustrates the increasing costs of structural framing as the bay sizes increase beyond common 20 feet by 20 feet. In normal applications the larger bay sizes provide lower operating costs.

An integral component of the structural framing of an industrial building is the columns which serve as vertical support for the roof structure, the walls, and the process and materials handling equipment. The columns of a building are of particular interest since their placement determines the flexibility of the building. The interior columns must present a minimal interference to the location of process equipment and the movement of materials and personnel through the building.



Square Feet Per Bay with 20 Feet Eave
(Standard Bay Sizes)

Figure 8. Structural Framing Costs Related to Bay Size[7]

During the layout phase of the build-design, the location of interior columns and equipment can be determined by various procedures, and should reflect consideration of changes in the process and the location of equipment. Columns normally denote the boundaries of bays, and bays are normally dimensioned in "standard" sizes, with the cost of some less than others. From Figure 9 it can be seen that the 20 by 30 foot bay is the least costly (in construction cost), with the cost increasing as the bay size, and supposedly the operating efficiency, increase. As the bay size increases so also does the flexibility of the building, due to the larger uninterrupted area which allows for greater freedom in altering the location, size, and type of process equipment. Hence, the selection of the bay size must consider the present and future requirements of the building and the cost of providing for larger bays.

Related to the columns is the height of the roof. As the height of the building increases, the cost of construction, heating, cooling, and lighting also increases. The advantages of increased height are the generally increased safety (better ventilation, less crowding of equipment, etc.), efficiency (modification, expansion) and the flexibility of the process inside the building. Therefore, the decision on the building height is dependent upon the type of process to be enclosed (i.e. the size of process equipment, type of materials handling and equipment, the size of the product, etc.) and the probability of future alternations to the product or process equipment which might require greater height, but also considering the increased construction and operating costs associated with

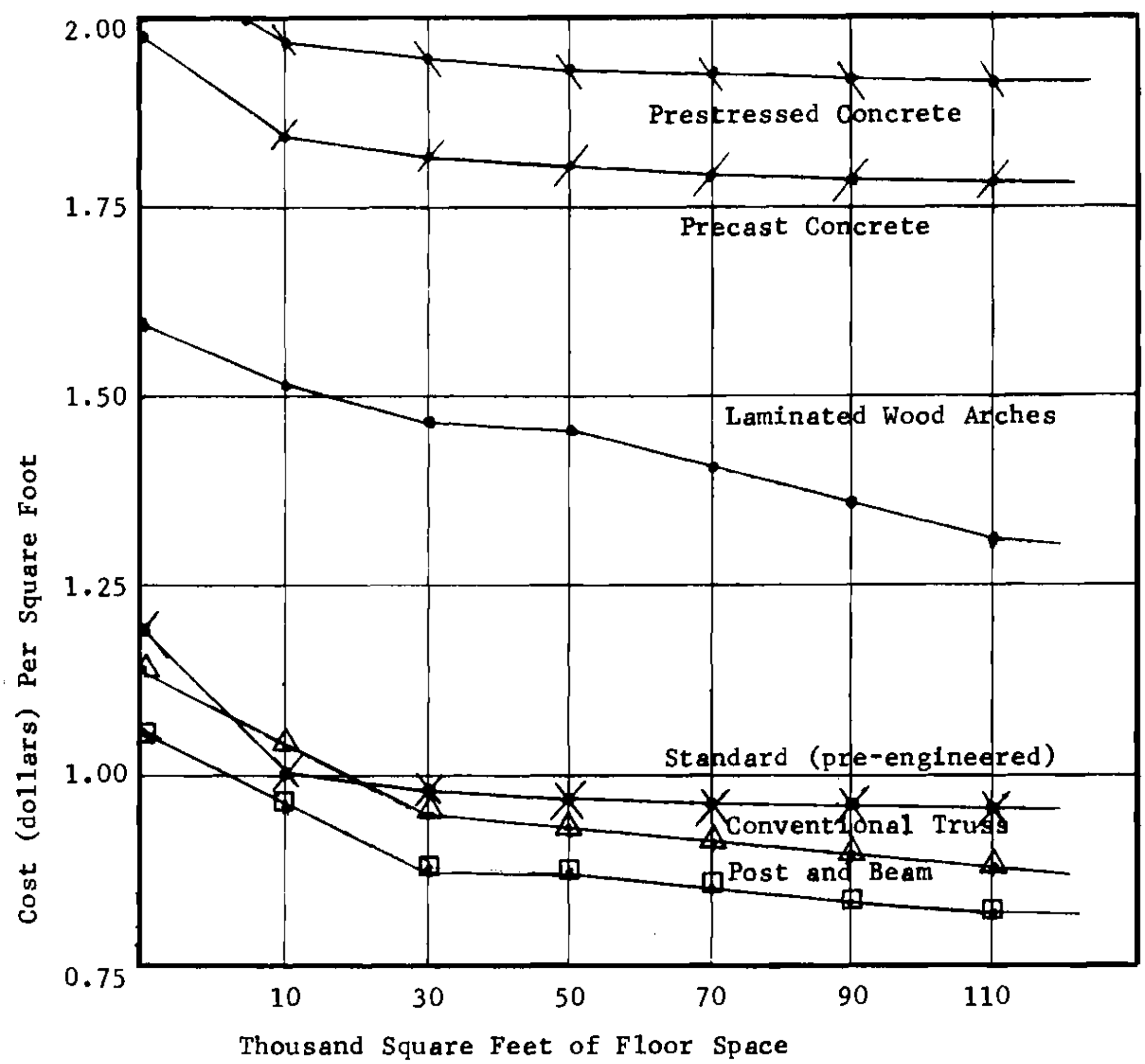


Figure 9. Structural Framing Cost Versus Floor Area[7,8]

increased building height.

The materials of construction for structural systems reflect both the operating environment created by the enclosed process and the desired investment by the owner. Table 3 shows the predominant materials used in the structural framing in industrial buildings, their applications, advantages, limitations, and approximate costs, while Figure 9 illustrates the cost trends of various materials as a function of the floor space.

Such special purpose materials as aluminum and stainless steels are available but at a substantial increase in procurement and erection costs, since they require special welding techniques.

As noted in Table 3, steel is susceptible to fire crippling, or structural failure in the intense heat of a fire. In buildings housing processes with potential high heat fire hazards, the use of concrete (reinforced or prestressed or post-tensioned) or concrete encased steel members will greatly reduce the threat of structural failure during a fire and will reduce the insurance and maintenance costs of the building. This effect can also be accomplished by spray coatings of asbestos or vermiculite of suitable thicknesses. These preparations also serve to lessen the accumulation of condensation on structural members.

Because they are combustible, laminated or sawn heavy wood timbers, which provide a relatively low cost solution to fire damage and the threat of structural failure during fires, are discouraged where other materials are applicable. As illustrated in Figure 10, wood retains its structural integrity much longer than unprotected

Table 3. Summary of Structural Framing

Material	Application Comments	Cost Per Sq. Ft.	Cost Index
Mild Steel	Dominant material, wide range of standard sizes and shapes, great versatility in fabrication and expansion modification, susceptible to corrosion and heat crippling.	\$0.85-\$1.40	1.0
Prestressed Concrete	Corrosive or sanitary processes, economical load-weight span of 60 feet, long, low maintenance life, inflexible for modification, limited economy on short spans, fire resistant, non-crippling in heat.	\$1.85-\$2.50	2.0
Reinforced Con-Crete	As above only more limited as to loading (horizontally) and span length.	\$1.35-\$1.50	1.6
Laminated Wood beams and arches	Chemically treated to resist fire, rot, insect, and corrosion. Spans to 120 feet, limited loading and modification. High transport cost.	\$1.30-\$1.60	1.6

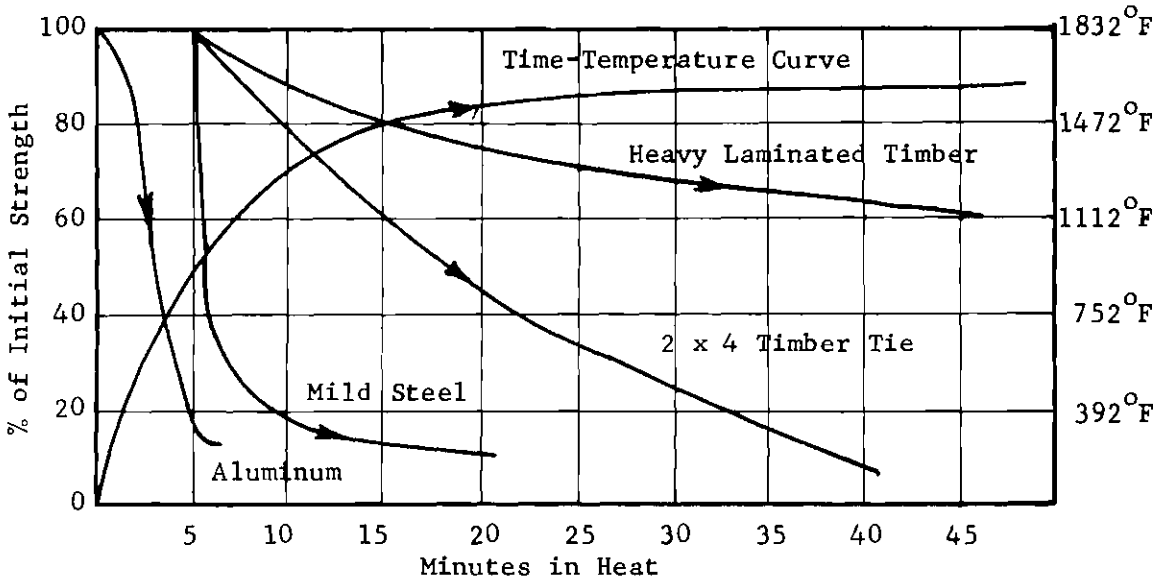


Figure 10. Structural Strength Under Intense Heat[9]

metals. Such metals lose strength due to softening under prolonged exposure to intense heat, but while wood may ignite (at 482°F) it retains the strength of that wood as yet unconsumed. Hence, in spite of intense heat, the wooden frame building remains structurally sound for a longer period allowing additional time for evacuation of personnel and equipment and for fire fighting; in some cases the structure of the building can be restored to near-previous condition with minimal replacements. However, insurance rates reflect the combustibility of the wood rather than the above noted advantages.

Walls and Interior Partitions

As noted previously, the exterior walls of present day industrial buildings are typically non-load bearing, primarily to facilitate expansion. Although these walls carry no significant loads vertically, they are subjected to many forms of horizontal force (i.e. winds, impact from materials and vehicles, or sustained pressure of leaning or loose materials), as well as the deteriorating effects of the enclosed process and the external environment (e.g. rain, sunlight, airborne pollutants, etc.). Masonry materials provide the most durable exterior walls but at a substantial increase in cost over metal walls. Table 4 lists the applications and costs of various wall materials. In many processes the durability, low maintenance, good insulating qualities and appearance of masonry overshadow the increased cost of purchase, erection and removal in the event of expansion. Typical masonry wall materials are brick, concrete block and brick, brick veneer, concrete precast panels, glass block, wood veneer, and

Table 4. Common Industrial Wall and Siding Material[10,11]

Material	Application	Cost Per Sq. Ft.	Cost Index
	Ease of Expansion - Metal Buildings		
Corrugated Galvanized Steel (0.026")	Neutral and heat environment, w/coating intact, resists rust.	\$0.48	1.0
Corrugated Aluminum (0.026")	Neutral and humid environments, resists rust, light weight, ductile.	\$0.62 \$1.30 (insulated)	1.3 2.7
Corrugated Asbestos	Corrosive, humid, and heat environments, heavy, nonductile (brittle), low heat transfer.	\$0.72	1.5
Type 316 Stainless Steel (26 Ga.)	Resists most corrosives (except caustics), ease of installation and expansion, ductile, heat and humid environments.	\$0.85	1.63
	Ease of Expansion - Masonry		
6" Reinforced Concrete	Resistant to oils (mineral), alkalis, organic solvents. Good appearance, good impact strength, heavy. Heat and humit environments.	\$1.20	2.5
8" Hy Wt Concrete Block	Restricted Expansion, low heat transfer, good appearance, good strength.	\$0.87	1.8
8" Lt Wt Concrete Block		\$0.83	1.7
12" Lt Wt Concrete Block		\$1.12	2.3
8" Block Concrete w/4" Common Brick		\$1.87	3.9
4" Common Brick		\$1.06	2.2

many combinations of these. Aluminum, galvanized steel or iron, or corrugated asbestos siding materials provide adequate, low cost walls which are easily removed in the event of building expansion, but are also susceptible to damage during removal. Metal panels are now available with thermal insulation similar to that used with the roofing materials. Table 5 lists the thermal transfer coefficients for common wall and partition materials.

In the design of industrial buildings, many combinations of various forms of exterior wall materials can be devised to minimize initial investment and provide for appearance, durability, expansion, and insulation. Metal and masonry wall systems are used in conjunction with translucent plastic panels and windows to improve the lighting efficiency. The choice of wall materials requires an evaluation of requirements for strength, durability, cost, appearance, and the probability of expansion.

Interior walls and partitions are used in industrial buildings for isolating offices from plant activities and other offices and for isolating distracting or harmful production activities from the other production areas. In the plant area the type of wall to be considered is a function of the activity to be isolated. For example, arc welding can be shielded from other production personnel with a light weight fabric, wood or metal partition; while the isolation of a noise source would require a heavier, acoustically absorptive material such as concrete block, or plaster baffles suspended from the roof structure.

Since interior walls and partitions interfere with the flow of production, materials, communications, light, and air, they may increase

Table 5. Heat Transfer Coefficients For Common Methods of Wall Construction[12]

Material	Insulation			Material	Insulation		
	None	½"	1"		None	½"	
3/8" Corrugated Transite	1.16	.34	.27	8" Solid Concrete	.70	.26	
3/8" Flat Transite	1.10	.33	.26	12" Solid Concrete	.58	.24	
Corrugated Sheet Iron	1.40	.36	.28	8" Concrete Block	.56	.24	
Asbestos Coated Metal	1.02	.39	.24	12" Concrete Block	.50	.22	
Corrugated Aluminum	1.30	.44	.26	8" Cinder Block	.41	.21	
3/4" Wood Siding	.58	.47	.27	12" Cinder Block	.38	.20	
8" Hollow Tile	.40	.20		4" Brick-8" Concrete Block	.40	.18	
12" Hollow Tile	.30	.17		Glass	1.13		
8" Brick	.50	.22		Wooden Doors	1.13		
12" Brick	.35	.19		Steel Doors	1.30		

the cost of such activities. Therefore the use of interior partitions should be limited to those instances in which their benefit will justify the cost of installation and the increased cost of those activities experiencing any interference from the partitions.

Roofs

Industrial roofs can be conveniently divided into two groups: (1) roof only and (2) roof decks with bonded coverings guaranteed for 15 to 20 years.

The term "roof only" applies to roofs of corrugated metals such as aluminum, galvanized steel, stainless steel, and asbestos. The corrugated roofs can also be insulated, normally using a 1½ inch thick blanket of fiberglass insulating material between two corrugated metal panels. Such roof systems are used for sloped roofs as are found on rigid frame and truss frame structures. These sheets are easily installed and removed using a wrench, and afford adequate protection from the elements. The fastening of the sheets is critical lest they be pulled off by high winds. The sheets themselves are designed very close to the minimum acceptable building standards for live and dead loads, and can be damaged by foot traffic.

Roof decks with the 15 to 20 year bonded coverings are used primarily for flat or rounded (e.g. covering a bowstring truss) roof buildings and are normally supported either by open web joists, bar joists, or trusses. The support provided by a deck of wooden planks, gypsum slabs, locking panels, or vermiculite concrete, the choice of which is dependent upon the weather conditions in the area, the enclosed process, and the desired investment. The deck is then covered with several (three or four) layers of roofing felt and cold tar pitch (or asphalt). If the roof is to be subject to substantial foot traffic and/or used to reflect sun light, then the use of gravel to protect the tar and felts is common. Such roof systems are more expensive than the corrugated metal roof systems, but offer a longer useful life and superior heating and cooling properties.

Table 6 illustrates the cost and applications of the various types of roofing systems. Table 7 gives the heat transfer coefficients of various roofing systems.

Environmental Control Equipment

In industrial facilities it is often necessary to control such aspects of the environment as temperature, light, sound and air purity to provide an environment which will be appropriate to the process, product and employee productivity. In the selection of building design specifications the installation of the environmental systems needs to be considered to provide (1) adequate space and structural support for the proposed systems in or on roofs, walls, or floors of the building and (2) for maximum operating efficiency of the proposed systems.

Heating, cooling, and ventilation systems require support for their central operating units and the duct work for conveying the treated air. Insulation reduces the heat transfer coefficient of roof and walls, thereby reducing the required size of the heating-cooling systems and improving the operating efficiency of the systems,

Table 6. Some Common Industrial Roofing Materials

Material Roof Only	Application	Cost Per Sq. Ft.	Cost Index
Corrugated Aluminum (0.032")	Neutral and humid environments, resists rust, light weight, ductile. Ease of installation and expansion	\$0.67	1.29
Insulated		\$1.35	2.60
Asbestos (Corrugated)	Corrosive, heat and humid environments, resists rust, low heat transfer, non-ductile. Ease of installation and removal.	\$0.77	1.48
Corrugated Galvanized Steel	Neutral and heat environments, ease of installation, removal, w/coating intact resists rust.	\$0.52	1.00
Type 316 Stainless Steel (20 Ga.)	Resists most corrosives (except caustics), ease of installation and expansion, ductile, heat and humid environments.	\$1.25	2.40
Roof Decks w/20 yr. roofing			
Precast,Prestressed Concrete Planks	Long, heavy load spans (60 ft. or greater), resists fumes and spillage of mineral oils, alkalis, organic solvents, non-rust.	\$1.50	2.89
Double Tee		\$2.40	4.60
Gypsum - 2" Precast	Heat, neutral environments, good insulation, noise absorbent, brittle, no painting, low bearing capacity.	\$0.80	1.54
Steel Deck, 20 Ga.	Heat and neutral environment, high load and impact capacity, high heat transfer.	\$0.54	1.06
Steel Deck, 16 Ga.		\$1.28	2.46
Wood Decks, 3" Fir, White	Corrosive, heat and neutral environment, medium to high impact and load capacity, good insulating factor.	\$0.96	1.85
20 Yr Roof Systems			
Asphalt, gravel	Will not dissolve in water	\$0.19	
Tar, cold pitch, gravel		\$0.18	

Table 7. Heat Transfer Coefficients for Roofing Systems[13]

Material	Insulation			Material	Insulation		
	0"	1"	2"		0"	1"	2"
Corrugated Sheet Iron	1.10	.28		6" Concrete	.65	.22	.13
Corrugated Aluminum	1.30	.26		2" Gypsum	.58		
Built-up Roofs: Asbestos Coated Metal	1.02	.24	.14	2½" Gypsum	.38	.18	.12
				3½" Gypsum	.31	.16	.11
Flat Metal Roof Deck	.94	.24	.14	1" Wood	.49	.20	.12
Precast Cement Tile	.84	.24	.14	1½" Wood	.37	.18	.11
2" Concrete	.82	.24	.14	2" Wood	.32	.16	.11
4" Concrete	.72	.23	.13	3" Wood	.23	.14	.096

and also reducing the condensation of heating combustion products and air borne moisture on the ceilings, the underside of the roof and the structural members during cold weather. Roof height and the ratio of wall length to width are also critical since the building must be of adequate height and configuration for the process without creating increased wall area for heat transfer or excessive air volume above the working zone. Ventilation systems require wall or roof support for intake and discharge facilities. Ventilation can very significantly affect the operating efficiency of heating and cooling systems, so that consideration need be given to the necessity and type of ventilation system required and whether it can be installed as an integral part of the air conditioning systems.

The installation of heating and cooling systems for industrial buildings should be done only on the basis of a professional survey by air conditioning engineers, as such buildings are among the most complex to heat and cool. They require more exact calculations as well as considerable practical experience compared to installations in most other types of buildings because of the infinite combinations of heat gains and building configurations. The recommendation will be either that the entire plant be air conditioned or only those areas which will have either process requirements and/or sufficient worker density and probability of improved efficiency to justify installation. Each area under consideration for air conditioning (i.e. heating-cooling systems as well as separate systems) should be evaluated on the basis of:

1. System type

2. Initial cost

3. Operating (and owning) costs

4. Benefits

5. Return on investment

Space heating can be accomplished by several means depending upon personnel density, process requirements, available utilities (i.e. boiler capacity), temperature differential and both initial and operating costs. Table 8 lists various types of heating units prevalent in industry and the applications for which they are best suited.

Air conditioning systems are more expensive to install and operate than are comparable heating systems, but despite these costs they are not as difficult to justify as might be supposed. Personnel density and the sensitivity of worker productivity to summertime temperatures are practical criteria warranting consideration of air conditioning systems. These criteria are illustrated in the following example.

Example: An air conditioning system for year-round operation (heating in the winter and cooling in the summer) can be installed in an industrial building of average heat gain for approximately $5.00 per square foot. The operating costs of an adequately insulated, average heat gain application would be approximately $0.25 and the owning costs would be approximately $0.50 per square foot per year. If the worker density or skill density is equal to or greater than $40.00 (wages and benefits) per square foot per year, then the minimum increase in efficiency required to justify the installation and operation of an

Table 8. Industrial Heating Systems

System	Applications	Installation Cost/ft^2
High Temp. Water System	Used where steam boiler is available. Most efficient in well insulated, slightly ventilated buildings with low ceilings of 10 to 12 feet.	3.50-4.50
Gas Fired Unit Heaters	High worker density, adequate ventilation, low ceilings, located near sources of cold air (i.e. doors, windows, building seams, etc.)	2.00-3.00
Horizontal	Discharge located such that air flow is not obstructed by machines, partitions, columns, etc.	2.00-3.00
Vertical	Used in high ceiling buildings with horizontal obstructions.	2.00-3.00
Gas Fired Infrared Heaters	Used for heating the immediate surrounding surfaces in the path of the radiation. Not suited to large areas or when worker movement is out of radiation area. Used for uninsulated, heavily ventilated, or high ceiling buildings (greater than 12'). Low fuel cost for difficult to heat areas. Mounted locally or around periphery of area.	1.50-2.00
Electric Infrared Heaters	As above, but also where ventilation is inadequate. Infrared heaters warm floors and surfaces through radiation so that these surfaces become heat sources.	1.25-1.75

air conditioning system is approximately 1.9 per cent.

Table 9 illustrates the procedure for developing the minimum justifiable increase in efficiency required for the installation of a year-round air conditioning system.

As might be expected, the cost per ton of air conditioning is a function of the size (BTU or refrigeration tonnage) of the proposed unit. That is, as the size of the unit increases the cost per ton decreases. Table 10 lists the approximate costs per ton for several industrial-sized air conditioning systems.

When considering year-round air conditioning, insulation can always be justified. This is illustrated in the following procedure for determining the cost of insulation and its five year savings in air conditioning costs.

Figure 11A is an isotherm map of the United States. The numbers denoting each isotherm are based on the average number of degree days of heating and cooling with an average inside temperature of 70°F. Figure 11B portrays the cost of installing increasing thicknesses of insulation to various roof deck systems to obtain diminishing coefficients of conductivity ("U" factor).

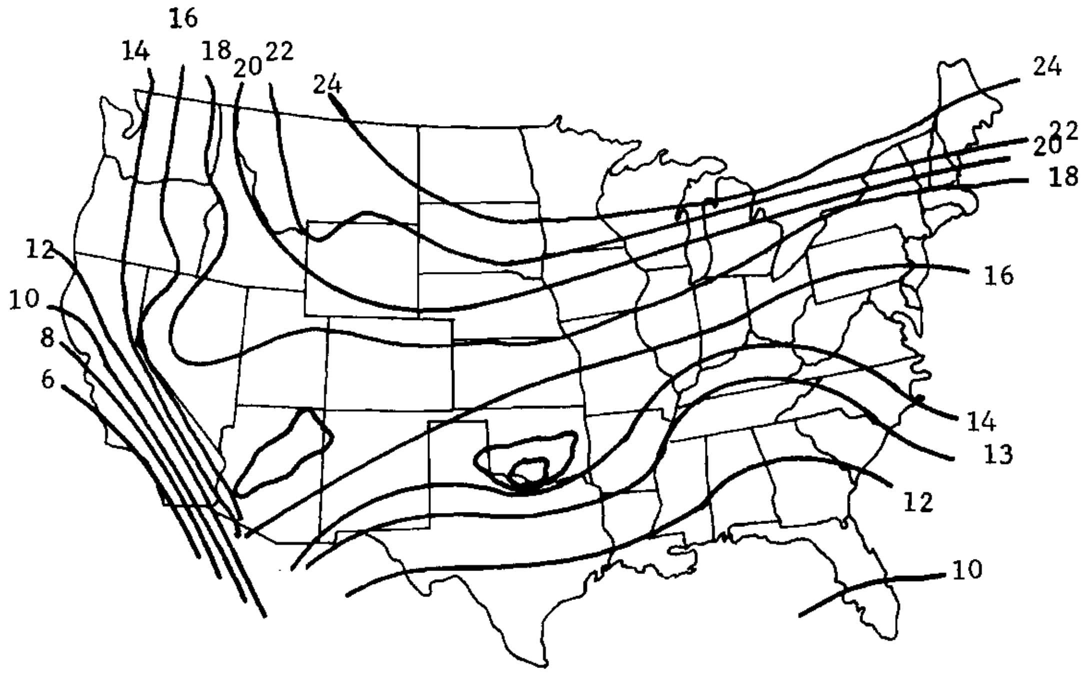
To determine the amount of insulation which will provide the optimum combination of heating and cooling economy and insulation cost, select the nearest isotherm above the geographical location of the proposed building from Figure 11A. Referring to Figure 11B subtract from the "U" factor for "0 inches" of insulation, the "U" factor for 1½ inches of insulation. Multiply this difference by the isotherm number to obtain the annual savings in heating and cooling costs

Table 9. Justifying Year-Round Air Conditioning[14]

Item	Example	Your Plant
A. Salaries and wages per square foot per year (including any fringe costs)	$40.00	
B. Initial Air Conditioning Costs per square foot	$5.00	
C. Principal and interest @ 5% for 20 years of (B x.08)	$0.40	
D. Insurance @ 1%, Taxes @ 1% (B x .02)	$0.10	
E. Owning costs per year per square foot (C + D)	$0.50	
F. Operating costs per square foot per year	$0.25	
G. Owning and operating cost per square foot per year (E + F)	$0.75	
Increased Efficiency Required to Justify Year-Round Air Conditioning G ÷ A	$\frac{G}{A}$ $\frac{\$0.75}{\$40.00} = 1.9\%$	

Table 10. Industrial Air Conditioning Systems[15]

Capacity of System (1 ton = 12000 BTU)	Cost Per Ton
25 Tons	$1,200
75 Tons	$1,070
100 Tons	$1,025
150 Tons	$1,000
200 Tons	$1,000
400 Tons	$910



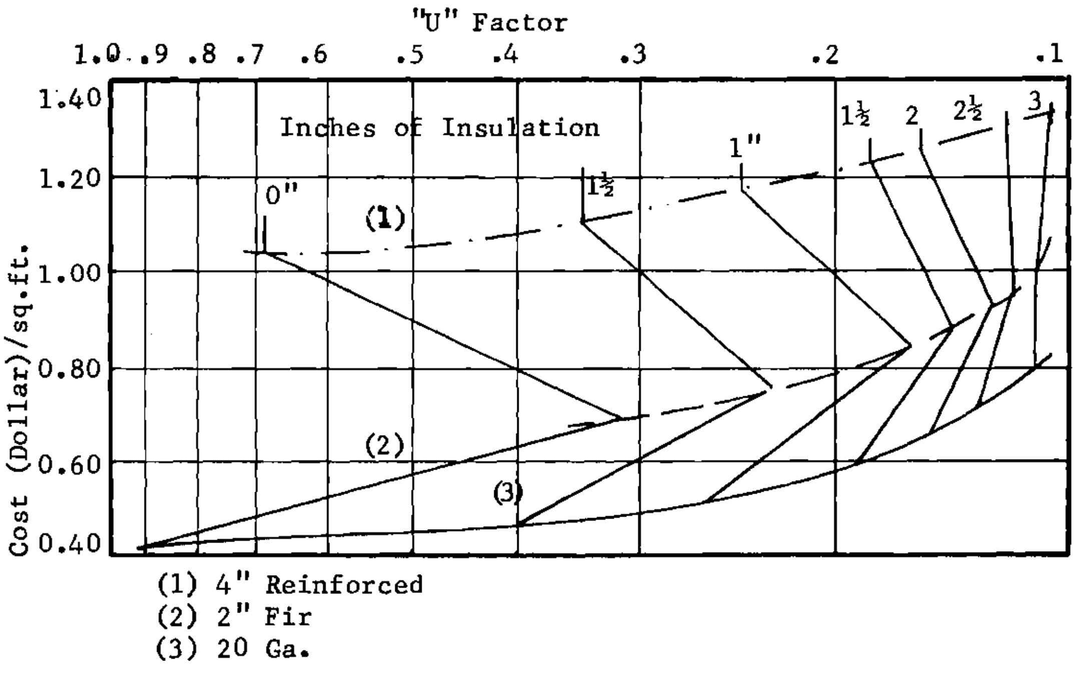


Figure 11A. Isotherm Map for Insulation[16,17]

Figure 11B. Costs and Savings Versus Insulation provided by $1\frac{1}{2}$ inches of insulation per square foot of roof or wall. If this amount is greater than the difference in roof system costs without insulation and the roof system with $1\frac{1}{2}$ inches of insulation, then $1\frac{1}{2}$ inches of insulation can be justified. This process can be repeated using different thicknesses of insulation until the savings and the additional cost of insulation are approximately equal.

As an example, select the isotherm in the Atlanta area which has a value of 13. The "U" factors for 0" and $1\frac{1}{2}$" of insulation for item 2 (2" Fir deck) are approximately 0.32 and 0.15 respectively. The difference of these "U" factors (i.e. 0.17) times 13 is $2.21, which is greater than the increased cost of the roofing system of $0.20 (i.e. 0.88-0.68). This can be repeated several times up to three inches of insulation. As can be seen, insulation is always justified if air conditioning and heating to a yearly average of $70^{\circ}F$ is required.

As noted, the evaluation of heating and cooling requirements should be performed by an experienced air conditioning engineer. Figure 12 illustrates the complexity of such an evaluation and the many aspects to be considered in designing a proper installation.

The ventilation of industrial buildings is necessary to remove air laden with combustion products and any fumes or particulate matter which might be harmful or discomforting to the employees. Although gravity ventilation is often used it is not always reliable as such ventilators rely on a negative pressure inside the building and, to some extent, the draft created by prevailing winds, neither of which are always available. Forced draft ventilation systems using ducts,

DESIGN DATA

OUTSIDE	SUMMER	INSIDE
95 F	DRY BULB	80 F
75 F	WET BULB	67 F
66.8 F	DEW POINT	60.3 F
39 %	PERCENTAGE HUMIDITY	50 %
37.81	TOTAL HEAT BTU PER LB. OF AIR	31.15
98.7	GRAINS OF MOISTURE PER LB. OF DRY AIR	78.2
F	WINTER	F

LATITUDE 40 TIME ____ AM 3 PM

WALL COLOR		ROOF COLOR		WINDOWS	
LIGHT	☐	LIGHT	☐	AWNINGS	☐
MEDIUM	☑	MEDIUM	☐	SHADES	☑
DARK	☐	DARK	☑	BARE	☐

SUMMARY OF HEAT GAINS

ITEM NO.	ITEM	SENSIBLE	LATENT
9	CONDUCTION	116,496	
17	EXCESS SOLAR	347,367	
18	DUCTS		
22	BODY	16,000	32,750
29	EQUIPMENT	184,000	
32	INFILTRATION	72,900	62,100
33	TOTAL SENSIBLE		X X X X X X X X
34	TOTAL LATENT		←
35	TOTAL HEAT GAINS		

SENSIBLE HEAT PERCENTAGE

36 $\frac{\text{ITEM 33}}{\text{ITEM 35}} \times 100 = \frac{736,653}{831,503} \times 100 = 88.6$ %

37 DRY BULB TEMP. AIR SUPPLY = 61.8 F.

38 WET BULB TEMP. AIR SUPPLY = 60.0 F.

39 RISE IN DRY BULB TEMP. OF AIR SUPPLY ROOM D. B. − ITEM 37 = 80 − 61.8 = 18.2 F.

40 TOT. AIR SUPPLY = $\frac{\text{ITEM 33}}{1.1 \times \text{ITEM 39}}$ = CFM

$\frac{736,653}{1.1 \times 18.2}$ = 36,850 CFM

HEAT LOAD OF VENTILATION AIR

41 NO. PEOPLE ____ X ____ CFM/PERSON = ____ CFM

42 CFM O. A. ____ X ____ BTU/HR/CFM = ____ BTU/HR

TOT. COOLING LOAD ON COILS & REFR. APPAR.

	ITEM 35	831,503
	PLUS ITEM 42	
43	TOT. COOLING LOAD BTU/HR.	831,503

TONNAGE EQUIVALENT OF COOLING LOAD

44 $\frac{\text{ITEM 43}}{12000} = \frac{831,503}{12000} = 69.2$ TONS

COOLING AND HEATING LOAD ESTIMATE SHEET

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THE TRANE COMPANY

LA CROSSE, WISCONSIN

DATE 8-15-57 JOB NO. T-215 EST. BY F. B. M.

NAME ACME INDUSTRIAL CORP.

ADDRESS 4528 S. 21st STREET

CITY & STATE CHICAGO, ILLINOIS

BRANCH OFFICE

ROOM ENTIRE BLDG. FLOOR FIRST SH. NO. 1

L'GTH 150 WDTH 75 HT. 12 VOL. 135,000 CU. FT.

CONDUCTION SENSIBLE HEAT GAINS AND LOSSES

ITEM NO.	ITEM	DIMENSIONS	AREA SQ. FT.	SUMMER U	SUMMER TD	SUMMER SEN. HT. BTU/HR.	WINTER U	WINTER TD	WINTER SEN. HT. BTU/HR.
1	EXTERIOR WALL GROSS	450×12	5400	X	X	X X X X X X	X	X	X X X X X
2	EXTERIOR GLASS (18×5×7)	+(2×8×7)	−2,058	1.1	15	33,957			
3	EXTERIOR WALL NET		3,342	.3	15	15,039			
4	PARTITIONS NET								
5	GLASS IN PARTITIONS								
6	FLOOR								
7	CEILING OR ROOF	75×150	11,250	.4	15	67,500			
8	MISC.								
9	TOTAL CONDUCTION GAINS & LOSSES			•	•	116,496	•	•	

EXCESS SOLAR HEAT GAINS

ITEM NO.	ITEM	DIMENSIONS	AREA SQ. FT.	U	TD	SEN. HT. BTU/HR.
10	WALLS FACING S. (12×75) −	(10×7×5)	550	.3	9	1,485
11	WALLS FACING W. (12×150) −	(18×5×7)−(2×7)	1,121	.3	5	1,681
12	GLASS FACING S.	10×7×5	350	1.1	8	3,080
13	GLASS FACING W. (7×7) +	(18×7×5)	679	1.1	77	57,511
14	ROOF	150×75	11,250	.4	63	283,500
15	SKYLIGHTS					
16	MISC.					
17	TOTAL EXCESS SOLAR HEAT GAINS					347,257
18	DUCT GAINS					

BODY HEAT GAINS

ITEM NO.	ITEM	SENSIBLE	LATENT
19	SENSIBLE NO. PEOPLE 25 X 240 + 50 X 200	16,000	
20	LATENT (QUIET) NO. PEOPLE 25 X 250		6,250
21	LATENT (ACTIVE) NO. PEOPLE 50 X 530		26,500
22	TOTAL BODY HEAT GAINS	16,000	32,750

EQUIPMENT HEAT GAINS

ITEM NO.	ITEM	SENSIBLE	LATENT
23	ELECTRIC LIGHTS 10,000 WATTS X 3.4	34,000	
24	SMALL ELECTRIC MOTORS (2 H.P. & SMALLER) H.P. X 4000		
25	LARGE ELECTRIC MOTORS (3 H.P. & LARGER) 5×10 H.P. X 3000	150,000	
26	ELECTRIC EQUIPMENT WATTS X 3.4		
27	GAS EQUIPMENT NO. X		
28	MISC. NO. X		
29	TOTAL EQUIPMENT GAINS	184,000	

INFILTRATION GAINS

ITEM NO.	ITEM	SENSIBLE	LATENT
30	ROOM VOLUME 135,000 CU. FT. X .54 SEN. FACTOR	72,900	X X X X X X X X X
31	ROOM VOLUME 135,000 CU. FT. X .46 LAT. FACTOR		62,100
32	TOTAL INFILTRATION HEAT GAINS	72,900	62,100

Figure 12. Heating-Cooling Evaluation Form[19]

hoods, and fans insure continuous, adequate ventilation. Ventilating fan manufacturers can provide data for designing systems to suit requirements of size, design, and construction materials. Table 11 lists the suggested rate of change for various building applications.

Ventilation also serves to reduce the damage caused by fires. Fire ventilators are normally of the automatic type with fused links, opening only when there is a fire. The likelihood of damage is reduced by venting smoke and heat from the burning area allowing close-in fire fighting, by drawing heat vertically thus reducing the lateral spread of the fire, and by providing an entrance for water streams. The location and size of fused ventilators should depend upon the location, potential sizes and intensities of fires in the building contents.

Lighting fixtures normally require little support for the illuminating elements, ballast, and controls but consideration of their location, method of support, and access should not be neglected. Efficiency in lighting refers not only to the operating efficiency of the lamp but also to the proper provisions for light distribution. This phase of lighting efficiency can be greatly enhanced by light colored walls, ceiling (or roof), and the interior exposed surfaces of structural members, which improves the reflection and diffusion of light. Windows, translucent plastic wall panels, and skylights (available in insulated, low heat transfer types) will improve the day time lighting efficiency of the building, but care should be taken in the choice of materials since some are of materials considered flammable by insurors or may contribute significantly to heat

Table 11. Suggested Rate of Air Change for Buildings[19]

Application	Minutes Per Cycle	Application	Minutes Per Cycle
Assembly Halls	5 to 10	Machine Shops	3 to 5
Boiler Rooms	2 to 4	Mills (Dye House)	2 to 3
Dry Cleaning Plants	1 to 5	Mills (Paper)	2 to 3
Engine Rooms	1 to 1½	Mills (Textile)	5 to 15
Plant Buildings (Ordinary Conditions)	5 to 10	Offices	5 to 10
Plant Buildings (Fumes, Moisture)	2 to 5	Pickling Plants	2 to 3
Forge Shops	1 to 3	Plating Rooms	1 to 5
Foundries	1½ to 3	Pump Rooms	12
Galvanizing Plants	1½ to 3	Shops - General	5 to 10
Garages	3 to 5	Shops - Paint	2 to 3
Generator Rooms	2 to 5	Substations, Electric	10 to 12
Glass Plants	1 to 2	Toilets	3 to 5
Gymnasiums	2 to 10	Transformer Rooms	1 to 5
Heat-Treating Rooms	½ to 1	Turbine Rooms	2 to 6
Kitchens	2 to 3	Warehouses	10 to 30
Laboratories	3 to 10		

gain and loss.

Proper lighting may greatly improve the productivity of workers by increasing production (up to 50 per cent in fine assembly work), by decreasing rejects (up to 35 per cent in detailed machine work) and reducing the number of accidents in the building. The cost of lighting is approximately $0.01 per square foot per foot candle for installation. Amortized over a ten year life, the owning, operating, and maintenance costs of lighting is $0.01 per hundred foot candles per hundred square feet per hour. Table 12 lists the suggested lighting levels for various industrial activities and Figure 13 displays the costs of operating lighting systems of various level of illumination.

Noise is an aspect of industrial buildings which is largely overlooked in the design of many plants. Excessive noise can cause injury to the ears and is increasingly becoming a compensable occupational hazard, with recent awards as high as $16,000. Excessive noise also has a fatiguing effect upon employees by reducing their productivity, causing them to be irritable and unattentive to their work, and increasing worker absenteeism. Noise also makes communications difficult, and creates a hazard for personal injury.

Noise-producing equipment and processes can either be muffled or isolated from the more populated areas of the plant. The isolation can be effected not only by proper location but also by acoustical baffles which can be suspended from the roof structure. Noise absorbing materials can be planned for walls, ceilings, and floors of the building. Concrete foundations or floors on which are mounted heavy, noisy equipment should be isolated by an air gap from other floors and

Table 12. Suggested Lighting Levels for Industrial Buildings[20]

Sight Task	Examples	Recommended Foot Candles
Casual	Inactive Storage, Ordinary Inspection	30
Rough	Bulky Storage, Labeling & Wrapping, Riveting	50
Medium	Drafting, Fine Storage, Inspection, Medium Assembly	100
Fine	Difficult & Color Inspection, Fine Machining	500
Extra Fine	Minute Inspection, Welding, Extra Fine Assembly	1000-2000

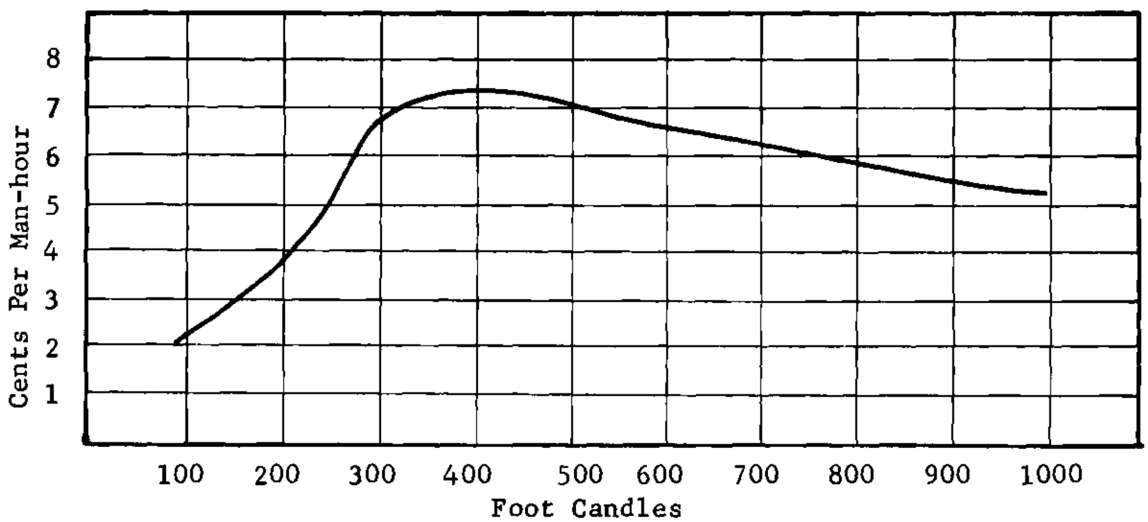

Figure 13. Lighting Costs as Related to Illumination Levels[21]

foundations to eliminate transmission of noise vibrations. Such machinery could also be mounted on vibration pads if machine alignment is not critical. Noise can also be vented out of the building to some degree, and noise outside the building is effectively baffled only with concrete block (or equal) walls, and not by trees and shrubs.[22]

Although the layout phase of the building design should consider noise in the location of equipment, processes, and personnel, the building designer must also be aware of critical noise areas and make proper acoustical provisions in the selection of building components.

CHAPTER IV

ANALYSIS OF OPERATING COSTS

After completing the construction of a building, there are incurred such costs as are associated with maintaining it and carrying on operatings within the building. As implied previously these costs are very much a function of the design specifications incorporated in the building. In the following chapter the more significant operating costs, which are also a function of the design specifications, will be analyzed. They include:

1. Maintenance
2. Insurance
3. Environmental Controls
4. Expansion

Under these headings are discussed the construction features related to each of the operating costs and the operating cost trends associated with these features.

Maintenance

From the time it is completed, the building starts to deteriorate, requiring maintenance to keep it functional as long as possible. Although this deterioration is inevitable, the speed at which it progresses can be regulated through (1) proper design specifications and (2) proper maintenance, the cost of one normally being inversely proportional to the other. The cost of normal maintenance for an industrial building (i.e. for foundations, floors, walls, structural and roof as distinct from utilities such as heating, lighting, etc.) amounts to from \$0.40 to \$0.70 per square foot per year, depending upon the building's height, age, materials and type of construction, and the process enclosed by the building.[23] The above approximation of the maintenance costs is an industry average for housekeeping as well as repair and replacement for the year 1969.

Housekeeping normally consists of cleaning floors, removal of trash, cleaning windows and walls, and such activities as are carried out under a daily, weekly, or monthly schedule. Repair and replacement refers to the mechanical repair of damaged building components such as repainting of structural members, repair of floors, replacement of damaged, worn, or corroded wall, floor, and roof sections.

In some smaller enterprises, housekeeping and even building maintenance is performed by operating personnel during their slack working hours, while in larger enterprises these functions are allocated to a particular department. In the smaller enterprise, maintenance costs are difficult to record in standard accounting practice. In the larger enterprise, with separate maintenance and housekeeping departments, these costs are normally available only through an intensive, thorough audit, and then they are seldom published. In order to develop realistic costs for the maintenance and housekeeping functions, a survey was made in the central Georgia area. Of the industries surveyed only The Coca-Cola Company had such data available. Some of the others were able to make intelligent estimates. These are included in the Appendix. On the whole the attempted survey indicates that most building owners are not aware of the cost of maintaining their buildings.

Further research and the survey indicates that capital invested in the initial cost of construction, with proper consideration for operating environment, significantly reduces the cost of maintenance through the life of the building. This trend is illustrated in Figure 14, derived from the survey and available literature. For example, in a building enclosing a corrosive process, the use of steel framing would require greater maintenance time in preparation, down time and re-coating than a wood laminated frame, which in turn would be greater than a comparable frame of concrete in certain types of corrosion.

Also of interest is a breakdown of the individual costs included in the maintenance cost of industrial buildings. Figure 15 illustrates such a breakdown for an average of eleven food processing plants over a six year period. On either side of the "average" column are two examples of representative extremes. Although these figures are for food processing plants, the relationships are typical of most industrial buildings, but the actual cost of each item will vary significantly from one industry to another and from one system of materials to another.

Insurance

Industrial fire and property insurance costs the average enterprise from four to seven cents on every 100 dollars invested in buildings and equipment covered by the insuror. Business interruption insurance costs

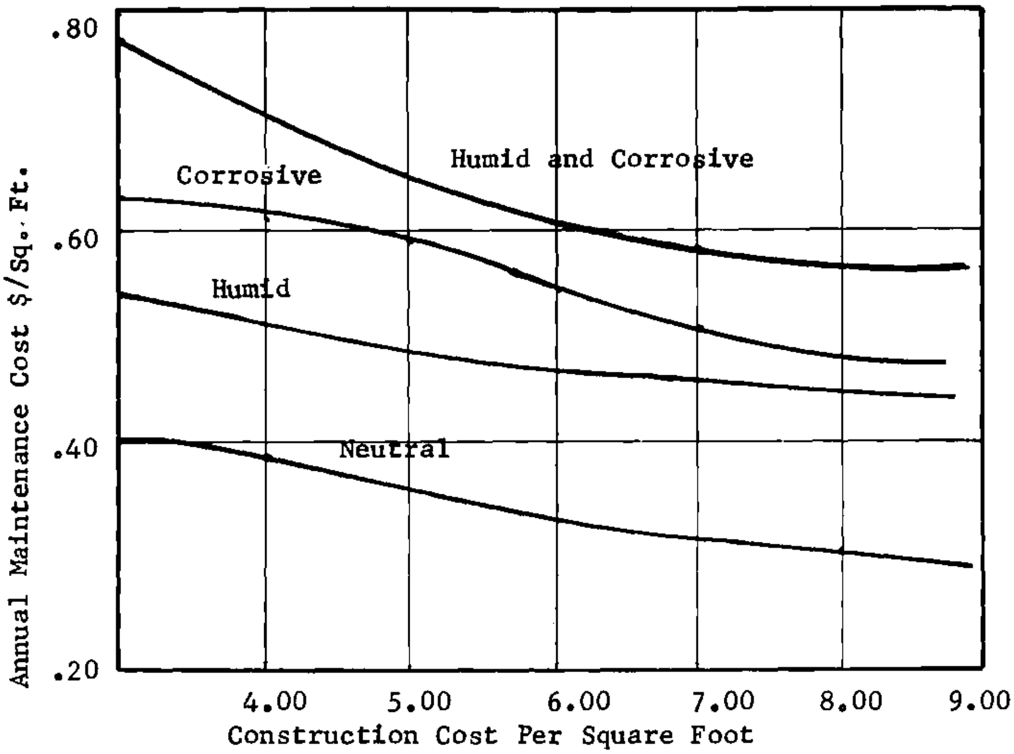

Figure 14. Maintenance Cost Related to Construction Costs

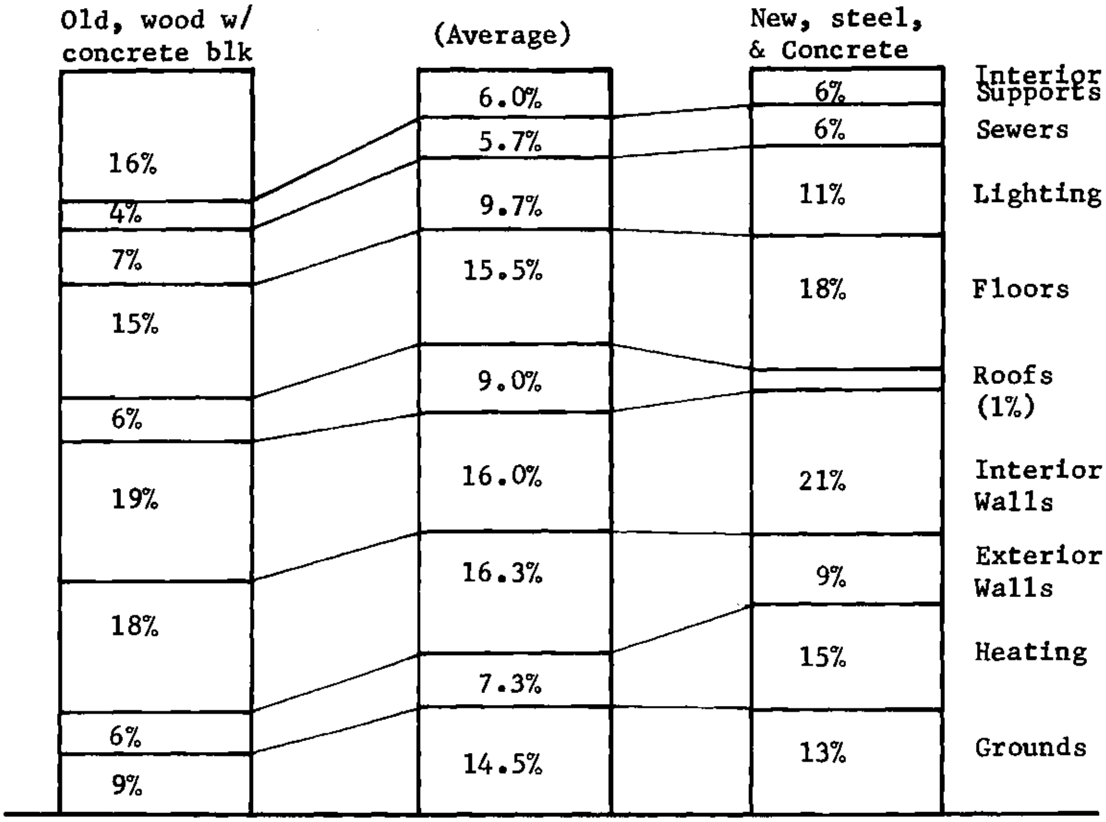

Figure 15. Maintenance Cost for Building Components[24]

the enterprise from three to six cents on every 100 dollars of potential loss in revenue.[25] The cost of insurance coverage is a function of the process enclosed by the building (including process materials), the type and materials of construction, the configuration of the building (i.e. height, enclosed area, etc.) and the protection system(s) provided by the enterprise. The actual cost of insurance is determined by an evaluation and assessment of the above items by an agent of the insurance firm.

Fire protection systems are not normally a part of the basic design specifications of a building, but they will be discussed briefly to present the benefits and costs of fire protection. The installation of the proper automatic fire protection system (water sprinkler, carbon dioxide fog or dry chemicals) in a building housing flammable materials can reduce the cost of premiums for fire insurance from 25 per cent to 90 per cent. This premium reduction reflects the fact that a water sprinkler system in a proper application is effective in controlling 75 per cent to 95 per cent of all fires in the sprinklered area.[26]

Portable fire extinguishers are effective for controlling small fires when the personnel are available to detect the fire and operate the equipment, but are not considered adequate protection by the insurance companies. Hence the emphasis for 24 hour fire protection is on the automatic system.

Of the automatic type systems the water sprinkler system is the least expensive, but the probable water damage to the contents of the building, may increase the insurance premiums for contents to the point that they equal or exceed the cost of insurance for the building. There are available carbon dioxide and dry chemical systems which are less damaging to building contents and which are effective against a wider range of fires (i.e. for petroleum and electrical fires). However, they are considerably more expensive than water sprinkler systems. Chemical and CO_2 systems require automatic fire doors which allow for the possible entrapment of personnel in sealed off areas which are to be flooded with smothering gases or foams. The cost of installing a water sprinkler system is approximately $0.40 per square foot (regardless of ceiling height) while a chemical system would cost $350 to $450 per thousand cubic feet (or $3.50 to $4.50 per square foot for a ten foot high ceiling).

The limits of operation of conventional fire fighting equipment is reflected in the increased premiums for buildings whose height or overall width exceeds the effective "throw" of a stream of water from a truck mounted pump, which is about 75 feet. For buildings with heights greater than 70 feet or widths (without access) greater than 150 feet, the insurance rates can be as much as 75 per cent greater than buildings within these limits.

Considering the innumerable factors to be weighed in developing a premium rate, it would be ludicrous to attempt to provide a table for determining insurance premium savings as they are related to building construction. Also premium savings from upgrading the structure and materials of a building seldom justify the cost of upgrading. (The substantial decreases in premium results from upgrading the protection of the building, such as installing an automatic water sprinkler system.) Another difficulty in attempting to generalize fire insurance rates is that the rate structure varies with the type of company the enterprise insures with. For instance, a class of mutual fire insurance company (which is insuror owned and normally non-profit) often quotes rates as high as $0.65 per $100 (insured) but issue annual rebates or dividends equivalent to as much as 90 per cent of the premium for the installation of automatic sprinklers or superior construction features. The rebates are paid from excess funds (after paying for claims, business expenses, and contingency reserves); hence, the primary aim of mutual insurors is fire prevention and protection, not indemnification for incurred losses. The insured of mutual insurors are actually stockholders and are liable (proportionally) for claims in excess of the income from premiums and investments. On the other hand, stock insurors who are profit oriented provide primarily for loss indemnification, requiring slightly higher premiums (in most cases) but with no risk to the insured of unexpected assessments should the annual claims exceed the annual income. Like the mutual companies, the stock companies are interested in fire prevention and protection, but no so intensely as are the mutual companies.

Table 13 is a general guide to the rating of materials and construction as regards fire hazards, but without considering protection provided by the enterprise and the occupancy of the building. The more hazardous materials (which tend to have higher premium costs) are assigned the higher of the ratings between 1 and 10.

Expansion

It is the aspiration of the competitive enterprise that the

Table 13. Relative Insurance Risk Rating for Building Components[27]

Building Characteristics	Rating	Classification	Comments
<u>Framing</u>			
Rigid	2		
Truss	0		
Beam & Post	1		
<u>Materials</u> (Framing)			
Steel	4	Non-combustible	Intense heat can cause structural collapse.
Unprotected wood	10	Combustible	Wood retains strength until consumed.
Fire Resistant treatment	3	Non-combustible	
Concrete	0	Fire resistive	
Steel (encased in concrete)	0	Fire resistive	Same rating if encased in Perlite or plaster brd.
<u>Walls</u>			
Aluminum	4	Non-combustible light	Tend to collapse in heat-higher replacement cost.
Steel (galv)	3	"	" " "
Asbestos	2	"	" " "
Concrete	0	Non-combustible heavy	
Brick & Block	2	"	Some danger due to collapse after sustained heat.
Wood	10	Combustible	High repair cost.
Metal-wood	7	Combustible	

Table 13 (Continued)

Building Characteristics	Rating	Classification	Comments
Roof			
Aluminum	4	Non-combustible light	Tend to collapse in heat-higher replacement costs.
Steel (galv)	3	"	" " "
Asbestos	2	"	" " "
Built-up: Old Asphalt	10	Fast burning	Heat induced boiling of asphalt-produced highly flammable fumes.
New	3	Fire resistant	
Steel	3	Non-comb. (heavy)	
Concrete	0	Fire resistive	
Gypsum	0	Non-combustible heavy	
Wood	10	Combustible Fast-burning	

demand for their products or services will increase and that the enterprise will grow and prosper. But because the requirements of the future are largely unknown and the funds for investment in "bricks and mortar" are normally limited, the initial physical facilities are usually limited in size to the immediate needs. However, because increases in the demand for products and services will require expansion, the selection of basic building specifications should consider the economics of expanding the building. The economics of expansion are founded primarily on the cost of removing and/or reusing existing building components, such as walls and structural members.

If the direction of expected expansion is vertical, the columns and roof design should be of a material and design to facilitate expansion. The columns should either be of steel or reinforced concrete and of proper strength to bear the increased load of the additional floors. The roof structure should, of course, be flat and of sufficient strength as might be found in an open web joist or bar joist system. Additional floors may be suspended from the new roof structure if the original roof is of insufficient strength, but this entails a substantial increase in costs.

Horizontal construction requires considerable foresight concerning the flow of materials and activities as they are reflected in the location and design of walls and columns. Outside columns should be designed to carry the roof structure of an adjacent expansion and located such that aisles, materials handling equipment, and process activities are not impeded from entering the new area. Walls on building faces subject to expansion should be easily removable and, preferably, reusable. The Coca-Cola Company has found that six-inch reinforced concrete tilt-up panels reduce the cost of expansion as much as 25 per cent on a $10.00 per square foot building.[28] These walls are attached so that removal is facilitated and they can be put aside during expansion construction to be replaced later. The concrete is much more durable and only slightly more expensive when insulated then the insulated metal panels. The concrete tilt-up panels are normally limited to first floor expansion with the upper levels being of metal panels.

Environmental Controls

The extent of environmental control installed in an industrial building is a function of the sensitivity of the productivity of the process to worker comfort and, in special cases, to the purity and cleanliness of the environment. In processes requiring worker concentration and intricate or delicate manipulations, worker productivity is seriously hampered at room temperatures above 82°F and below 60°F (most comfortable 69-73°F).[29] If it is decided that heating and/or cooling are desirable, the design specifications for the building should reflect consideration of the economies available from controlling the environment inside the building. Such economies take several forms: (1) the configuration of the building; (2) the materials of construction for the walls, roof (i.e. insulated, uninsulated, concrete, wood, metal, etc.), and in some cases, the floors, as well as windows, doors, and ventilation: and (3) internal heat sources and heat sinks. These economies are manifested not only in the operating costs of the system, but also in the initial investment for the system.

The materials of construction of the walls and roof greatly affect the economy of operation of the controlled environments because these surfaces are interfaces with either heat sources or heat sinks, from or into which heat transfer takes place. The use of the proper materials at these interfaces will reduce heat loss or gain, and hence, the cost of operating the environmental control system can be reduced as much as 90 per cent in some geographical areas.

The cost per square foot of heating or cooling a building of a given area will increase with the height of the building and the length to width ratio of the walls. The increase in height or ratio of walls, also increases the wall surface subject to heat transfer.

The heating and cooling costs for a particular building can be estimated from the charts supplied in Figures 11A and 11B.

CHAPTER V

EVALUATION AND SELECTION OF THE BASIC DESIGN SPECIFICATIONS

Having analyzed the two basic cost functions pertinent to the design of industrial buildings (the initial cost of construction and the operating costs), they can now be related to one another through the application of basic economic tools. Although the tools are not complex, certain considerations must be made in their application to assure their comprehension and suitability. Hence, before presenting the evaluation and selection procedure, assumptions and justification for the assumptions will be discussed concerning these factors: the life of the building, the effects of inflation, taxation and interest, and the reliability of cost estimates for construction and operation.

Building Life

The "expected life" of an industrial building has several facets, each having some bearing upon the design decisions. The expected life can be defined by either or all of these factors:

1. The economics involving the value of the building, the land, and the contents of the building (fiscal depreciation);

2. The suitability of the building to the owners requirements (technical obsolescence);

3. The natural physical life of the building and its components (physical depreciation).

Although the validity and pertinence of each of the above is dependent upon the owner's specific application, some general statements may be helpful in determining an approximate building life for specific cases.

The suitability of a building for its owner's requirements can, to a limited extent, be controlled through knowledge of impending or expected changes in the processes to be enclosed. The building designers should have the benefit of such knowledge (if it exists) and should be aware of the building requirements engendered by possible changes in the process. This is necessary so that the building design can incorporate the necessary considerations for flexibility and expansion. Technical durability can be improved even by approximate knowledge of future area requirements, height requirements, support requirements, environmental control requirements, and requirements for the materials of construction. In the chemical industry, where the rate of depreciation is much greater than any other industry, the life of buildings seldom exceed 20 years; while many manufacturing industries enjoy building lives up to 40 years. An industry wide average is approximately 25 years.[30]

The relationship of a building to its site and contents over the expected life of the building is as unpredictable as the time, form and degree of technical obsolescence. If the value of the land should increase substantially, more profitable use of the land may be possible and desirable. By terminating the life of the building in favor of a more economically feasible structure, the building is considered to have fallen prey to economic obsolescence. In another instance, the resources occupying the building (i.e. personnel, equipment, and/or storage) may increase or decrease in value such that the building is no longer of suitable security, prestige or benefit or is no longer recovering its operating costs.

For simplicity, the natural physical life of the building and of its components is commonly considered to be equal. To justify this practice, the replacement of worn, damaged or deteriorated components is treated as "renewals" and considered as being a part of normal maintenance. The physical life of a building or its components is dependent upon the manner in which it is maintained; i.e., more or less maintenance may extend or reduce the life. Hence the use of a particular life span for determining operating costs carries with it an appropriate program of maintenance. Also it can be expected that maintenance costs will vary considerably with the selection of materials and with the life expected of those materials.

Inflation, Interest and Taxation[31]

In the past two decades, inflation of the world's currencies has become an accepted norm, such that the predicted rate of inflation is considered in some economic calculations to determine interest and return on investments. However, in this discussion the effects of inflation are considered to be self-equalizing, such that the costs of labor and materials, and construction and maintenance remain approximately proportional. The justification for this assumption lies in the use of currency, rather than barter, for the procurement of goods and services. Also, although the cost per unit of labor is constantly increasing, building technology advances and diminishes the amount of labor required for construction and operation. Therefore, although the money costs for an operation increase, the accounts receivable are payablein the inflated currency. Hence the proportionality based on the real costs of labor and material remains largely unaffected. This fact justifies the lack of consideration of inflation in the design evaluation procedure presented in this chapter.

During inflationary periods the rates of interest and taxation change so frequently that there is little value in discussing their provisions in detail or trying to consider them in the design evaluation of an industrial building. However, it should be noted that (other things being equal) the higher the effective rate at which taxes are paid, the lower the net rate of interest and the more worthwhile it is to invest initially in order to reduce operating costs (which provide less benefit under these conditions). It is interesting to note that the present federal tax structure covering corporations often reverses the commonly accepted belief that a higher initial investment resulting in a lower operating cost produces long term savings. The benefits of declaring annual building maintenance cost as a deductible operating expense outweighs the tax shelters for capital expansion. Actually, the financial staff of an industrial enterprise would be aware of any interest and taxation trends which would significatnly alter the cost program for an industrial building. They should inform higher management of any benefits which might be derived from a change in building policy, thus relieving the building designer of the responsibility for considering these factors in the design evaluation.

Reliability of Cost Estimates

The establishment of the construction and operating cost of building components is limited in accuracy by two types of prediction errors: sampling errors and errors in assumption. The construction costs used here were obtained from a literature search as well as by interrogation of local distributors of building materials, and will be assumed sufficiently accurate for this economic evaluation. Differences in construction cost may vary as much as 10 or 15 per cent, depending upon the contractor's interest in obtaining a contract. Within the limitations of this economic evaluation, the accuracy of the construction costs detracts little from the effectiveness of the procedure.

The operating costs for components, on the other hand, may suffer significantly, primarily from the sampling type error. Maintenance costs for specific materials in specific applications are almost non-existent in most industries. The information available is normally expressed in very general terms concerning the type and degree of maintenance performed. Also, some enterprises are more conscientious than others in their maintenance of plant buildings, adding to the sampling error, the error of assumption that maintenance costs can be defined as an average over the degrees of maintenance performed. Insurance, environmental control, and expansion costs are also affected by the same errors, and should be amended in this thesis whenever the user is knowledgeable in a particular area of costs.

Building Codes

Building codes are instituted to maintain standards of safety for occupants, as well as continuity of building quality and appearance, and as a guide or criterion for the buyer, contractor, and the insuror in determining the structural integrity, fire, health and disaster standards required of the building. Such codes affect the economic evaluation of industrial buildings by establishing minimal standards of acceptance, which may not only be represented by a minimum cost per square foot but may also provide for maximum building height and/or area, as well as the location of the building on the site and the use of, or provision for, public utilities. Building codes vary considerably in the minute details but in general are the same from one community or region to the next, so much so that it is neither feasible nor desirable to generalize on the subject. Instead, it is recommended that the designer be intimately acquainted with the building codes applicable to the location of the intended building site and use them as a safety guide.

Evaluation Procedure

The evaluation procedure in this chapter consists primarily of two distinct steps: (1) physical evaluation of components and (2) the economic evaluation of the proper (physically) component alternatives. The component tables in this chapter provide a systematic procedure for evaluating the suitability of each component for various applications. The results from the tables should provide the designer with one, two or more alternatives from which the economic evaluation will indicate the components satisfying the designer's investment criteria. The criteria for the selection of any one component from among the feasible alternatives will be the present worth of a total investment (i.e. initial costs and operating costs) over a period of time and at a rate of interest determined by management. As noted in Chapter 1, the lowest cost building (considering the present worth of the total investment) may not agree with management policy concerning building quality level. Hence, management may choose to ignore the lowest cost building in favor of a higher cost building for which the value of intangibles may justify the additional expenditure. In this case the total costs of the building alternatives will provide the management with a guide for determining the value of their specific intangibles.

In other instances the building shell will be considered by the owner as an unproductive expenditure which should provide an adequate occupancy for a minimal investment. Under this philosophy the least cost feasible building can be "developed" from the component tables presented here, by combining those components which are compatible with one another, as indicated in Figure 21 (which is applicable to the previous case also). The example following this discussion will provide a guide to the use of the tables and the economic evaluation.

Once the plant layout has been completed and approved then it can be used as the description of the physical requirements for the building. The evaluation of the physical components of the building can be guided by the following form: Figure 16. The form is completed as an example. The case used is an actual evaluation, in which the technology and cost records were known and available for

Example

Subject: Freeport Kaolin Company
Gordon, Georgia

Situation: Replacement of 50' x 300' x 20' high (eaves) standard steel truss, steel frame, galvanized steel roof and wall building with laminated wood rigid frame and truss and stainless steel roof and walls.

Application: The building houses eight 14' x 24' drum filters dewstering kaolin slurry. The slurry is heated and releases corrosive phosphoric and sulphuric acid fumes which are extremely corrosive to mild steel. The environment is hot (up to 110^{o}F), humid (95%) and corrosive. The building serves no intangible purposes being purely functional.

Comments: The above example was rather exceptional in that maintenance costs increased with time. The frame was being cleaned and painted at least once a year and the metal envelope was being replaced piecemeal. Replacement became necessary to prevent collapse of the structure upon the enclosed process. The noted maintenance cost does not include the cost of production loss time due to maintenance of the building and product contamination due to rust flakes. An estimate of these losses would approach 40¢/sq. ft./year.

Replacement of the building was accomplished with a minimum of production downtime by replacing only two bays at a time. While a section was being replaced, the process machinery in that area was housed in temporary structures erected under the actual building. The cost of removing the previous structure and erecting temporary shelters over the process amount to approximately $2.45/sq. ft., regardless of replacement structure.

Doors, windows, foundations and floors are not considered, as the cost of these items is equal for all alternatives. Only the basic envelope is considered here.

I. Shape (length to width ratio) - 6 to 1

Discussion Pages 16 - 18

Figures 1, 6, 7

Size: Length - 300 ft.

Width - 50 ft.

Eave - 20 ft.

Floor Space - 15,000 $ft.^2$

II. Miscellaneous Requirements:

Environment: (Heat (110^oF), Corrosive (mineral Acids), Humid (95-97 per cent)

Columns: No center columns

III. Component Selection

	Alternate #1 Truss Cost/Ft^2	Alternate #2 Rigid Cost/Ft^2	Alternate #3 Rigid Cost/Ft^2
1. Structural Framing Type Discussion, Pgs 23-27 Table 2 Figures 2,3,4,8,9 Summary, Pg 78	Truss	Rigid	Rigid
2. Structural Framing Material Discussion, Pgs 27-30 Table 3 Figures 9,10 Summary, Pg 78	Mild Steel	Wood Arch (Laminated)	Concrete Arch
3. Floors Discussion, Pgs 20-21 Table 1 Figures Summary, Pg 77	4" Concrete $0.33	4" Concrete $0.33	4" Concrete $0.33

		Alternate #1	Alternate #2	Alternate #3
4.	<u>Walls</u> Discussion, Pgs 31-33 Tables 4,5 Figures Summary, Pg 79	Galv. Steel $0.48	Stainless $0.85	Steel $0.85
5.	<u>Roofs</u> Discussion Pgs 34-36 Tables 6,7 Figures Summary	Galv. Steel $0.52	Stainless $1.25	Steel $1.25

6. <u>Controlled Environment</u>

A. <u>Insulation</u> for Heating and Cooling — (Not Justified - Only two Operators)
Discussion, Pgs 37-43
Tables 5,7
Figures 11A, 11B

B. <u>Ventilation</u> — (Natural Draft Fans)
Discussion, Pgs 43-45
Table

C. <u>Light Level</u> — (Existing)
Discussion, Pgs 45-46
Table 12
Figure 13

D. <u>Noise</u>
Discussion, Pg 47

IV. Alternative Building Component Systems

(Referring to Figure 23 [Component Capability Chart]), compare the various components in the above form to the other components, selecting the "systems" of components applicable to the requirements. The alternatives for economic evaluation are described below:

Cost

	Alternate # 1 Initial	Alternate # 1 Oper'n	Alternate # 2 Initial	Alternate # 2 Oper'n	Alternate #3 Initial	Alternate #3 Oper'n
Structural	1.05	0.45	1.50	0.0	1.25	0.0
Floor	-	-	-	-	-	-
Walls	0.48	0.20	0.85	0.10	0.85	0.10
Roof	0.52	0.25	1.25	0.05	1.25	0.05
Plus estimated production cost	-	0.40	-	0.0	-	0.0
Total	2.62	1.30	3.60	0.15	3.45	0.15

Cost Estimate

	Alternate #1	Alternate #2	Alternate #3
Frame	1.05	1.50	1.85
Walls ($/Sq.Ft. of floor space)	0.48	0.85	0.85
Roof	0.52	1.25	1.25
30 per cent (Contingency, contractor profit, etc.)	0.52	1.08	1.18
Total	2.72	4.68	5.13

Proposed Building Description	Construction Costs $/Sq. Ft.	Maintenance Cost $/Sq.Ft/Yr
1. Steel standard truss and frame with galvanized sheeting	2.72	0.85
2. Laminated wood rigid frames, with stainless steel sheeting	4.68	0.10
3. Concrete trusses with concrete block and stainless steel walls and roof. Special fasteners required.	5.13	0.10

A table of Rate of Return Calculations for the alternatives is shown below. (The cost of the building does not include the cost of removal of the old building.)

	Alternate #1	Alternate #2	Alternate #3
Facts			
Project Cost	40,800	70,200	76,950
Savings/(Annual)	0	17,250*	17,250*
Salvage Value	0	0	0
Economic Life	10 years	10 years	10 years
Tax and Royalty Factor	0.5	0.5	0.5
Calculations			
Gross Annual Savings	0	17,250	17,250
Less Depreciation	4080	7,020	7,695
	-4080	10,230	9,555
Net Savings (Annual Savings x 0.5)	-2040	5,115	4,777
Plus Depreciation	4080	7,020	7,695
Annual Cash Flow	2040	12,135	12,472
Payout Period, Years	20.0	5.8	6.16
Return on Investment	-	11.7%	9.9%

* Savings are determined by normal operation within the building and include the production savings which would be lost if the previous structure were duplicated.

Figure 16. Economic Evaluation of Building Components

such an evaluation; which is not always the case (as was illustrated by the attempted survey).

The summary charts are useful for evaluating the considerations which bear the greatest weight (i.e. insurance, maintenance, initial cost, etc.) upon each component. The ratios are approximate values assignable to each component alternative relative to the other alternatives.

Having completed the component selection forms (Figures 17-20), Figure 21 provides a guide to component compatibility which will assist in narrowing the available complete building alternatives to three or four "systems."

FLOORS		Environment: Neutral	Environment: Heat	Environment: Humidity	Environment: Acid	Environment: Alkaline	Environment: Mineral Oils	Environment: Organic Solv.	Environment: Wet	Traffic: Prolonged Stdy	Traffic: Lgt. Wheeled	Traffic: Hvy Wheeled	Traffic: Steel	Traffic: Rubber	Traffic: Hvy Impact	Modification	House-keeping: Basic	House-keeping: Clean	House-keeping: Sanitary	Cost: Initial	Cost: Maintenance	Cost: Housekeeping	Cost: Modification	Cost: Total Cost Ratio
Concrete Plus	Slab 4"	x	x	x		x	x	x	x		x			x			x	x		1.0	1.0	1.0	-	3.0
	Slab 5"	x	x	x		x	x	x	x		x			x			x	x		1.28	1.0	1.0	-	
	4" W/Emery,Hdnr.	x	x	x		x	x	x	x		x	x	x	x	x		x	x		3.30	1.0	1.0	-	
	4" W/Trap, Hdnr.	x	x	x		x	x	x	x		x	x	x	x	x		x	x		2.38	1.0	1.0	-	
	4" W/Asphalt	x		x					x	x	x					x	x	x		2.4	1.5	1.3	+	
	4" W/¼" Epoxy	x		x	x	x	x	x	x	x	x					x	x	x		4.85	1.5	1.4	+	
	2" Wood Block W/ Grd. Slab &Asphalt	x	x				x			x	x	x			x	x	x			3.64	1.2	1.3	+	
	Mild Acid Brick	x	x	x	x	x	x	x	x		x						x	x	x	3.14	1.1	2.0	-	
	Acid Proof Brick	x	x	x	x	x	x	x	x		x						x	x	x	7.10	1.1	2.0	-	
	Quarry Tile	x	x	x	x	x	x	x	x		x						x	x	x	4.24	1.0	3.0	-	

Figure 17. Summary of Industrial Flooring and Applications

Structural Framing	Environments				Structural Loading				Modification					Cost Ratios			
	Neutral	Heat	Humidity	Corrosive	None	Less 1 Ton	Less 5 Ton	Grtr 5 Ton	Load	Horizontal	Vertical	Standard Dimensions	Rapid Erection	Initial	Maintenance	Insurance	
Truss																	
Mild Steel	x	x			x	x	x	x	x	x	x			1.0	1.4	1.0	
Sawn Timber	x	x	x	x	x	x	x		x	x	x			0.9	1.5	1.3	
Rigid																	
Mild Steel	x	x			x	x	x		x	x		x	x	1.1	1.0	1.1	
Laminated Wood	x	x	x	x	x	x				x		x	x	1.6	1.2	1.3	
Prest'd Concrete	x	x	x	x	x	x	x			x		x	x	1.9	0.9	0.7	
Open-Web-Joist																	
Mild Steel	x	x			x	x			x	x	x	x	x	1.5	1.1	1.1	
Wood	x	x	x	x	x					x		x	x	1.0	1.3	1.3	

Figure 18. Summary of Industrial Structural Framing and Applications

Roofs	Environments				Heat Transfer			Time of Erection		Loading			Cost Ratios			
	Neutral	Heat	Humidity	Corrosive	High	Medium	Low	Unimportant	Rapid	Minimal	Medium	Heavy	Initial	Maintenance	Insurance	Total Cost Ratio
<u>Corrugated</u>																
Aluminum	x		x		x				x	x			1.3	1.3	1.3	
Alum. Insulated	x		x				x		x	x			2.6	1.3	1.4	
Asbestos	x	x	x	x		x			x	x			1.5	1.1	1.1	
Galvanized Steel	x	x			x				x	x			1.0	1.5	1.3	
Stainless Steel	x	x	x	x		x			x	x			5.0	0.7	1.0	
<u>Built-up Roof Systems</u>																
Wood, Timber	x	x	x	x			x	x			x		1.9	1.7	1.7	
Wood, Laminated	x	x	x	x			x	x				x	2.3	1.4	1.5	
Steel, 20 Ga.	x	x			x			x			x		1.1	1.5	1.4	
Steel, 16 Ga.	x	x			x			x				x	2.5	1.5	1.5	
Gypsum, 2" precast plank	x	x		x			x	x			x		1.5	1.1	1.1	
Concrete, Precast, Prestressed 5" plank	x	x	x	x		x		x		x			2.9	1.0	1.0	
Concrete Double Tee	x	x	x	x		x		x			x		4.6	1.0	1.0	

Figure 19. Summary of Industrial Roofs and Applications

		Environments					Heat Transfer			Expansion		Erection				Cost			
		Neutral	Heat	Humidity	Corrosive	Extr. Corrosion	High	Medium	Low	Low Cost	Difficult	Unimportant	Rapid	Strength	Appearance	Initial	Maintenance	Insurance	Total Cost Ratio
Metal	Galvanized Steel	x	x				x			x			x			1.0	1.5	1.3	
Metal	Aluminum	x					x			x			x			1.3	1.4	1.3	
Metal	Aluminum Insulated	x							x	x			x			2.7	1.4	1.4	
Metal	Asbestos	x	x					x		x			x			1.5	1.3	1.1	
Masonry	4" Brick	x	x	x	x						x	x		x	x	2.2	1.0	1.2	
Masonry	12" Brick	x	x	x	x						x	x	x	x	x	6.1	1.0	1.3	
Masonry	6" Concrete (Reinforced) Tilt-up Panel	x	x	x				x		x			x	x	x	2.5	1.1	1.1	
Masonry	6" Concrete Block	x	x	x	x			x			x	x		x		1.8	1.2	1.4	
Masonry	12" Concrete Block	x	x	x	x			x		x			x	x		2.4	1.2	1.5	
Masonry	4" Brick W/8" Concrete Block	x	x	x	x			x			x	x	x	x	x	4.6	1.0	1.6	
Glass	Single Pane	x	x	x	x	x	x					x			x		2.0	1.6	
Glass	Block	x	x	x	x	x					x		x	x	x		1.8	1.6	
Glass	Double Pane	x	x	x	x	x				x		x			x		2.0	1.8	

Figure 20. Summary of Industrial Siding/Walls and Applications

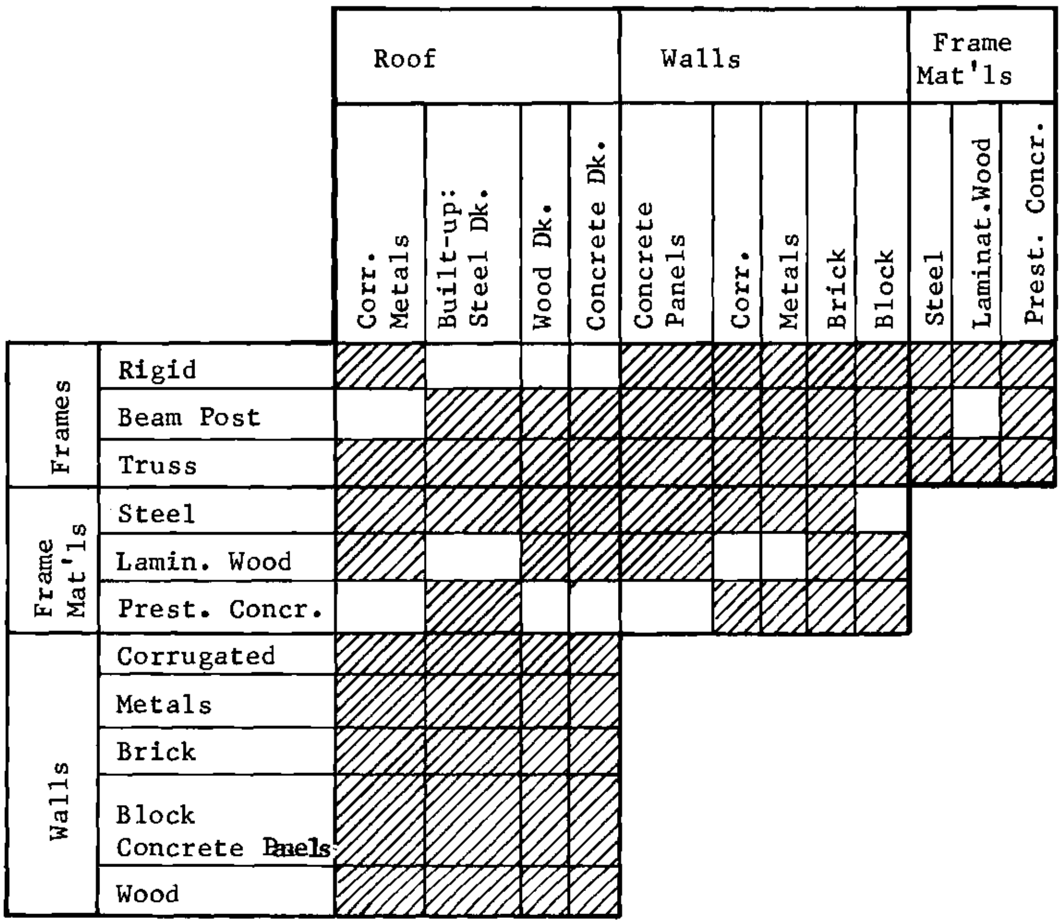

Figure 21. Component Compatability

CHAPTER VI

CONCLUSIONS

This thesis has developed a practical methodology for evaluating the design of industrial buildings on an economic criterion of which initial cost and operating costs are primary elements. The practicality of the procedure has been illustrated in an example and its limitations have been described in general terms. The conclusions concerning the procedure and the development of the procedure are:

1. A practical procedure for economic evaluation of industrial buildings is feasible.

2. The practicality of the procedure is not seriously jeopardized by trends in inflation, taxation and interest.

3. The practicality is jeopardized by changes in technology which alter the cost relationships of materials and labor for maintenance and construction.

4. The practicality of the procedure is limited by the need for periodic re-evaluation of the cost relationships.

5. There are very few plant managers who are aware of the costs for housekeeping and maintenance for their buildings.

6. There are very few plant managers and building designers who are properly aware of the consequences (in economic terms) of building designs.

CHAPTER VII

RECOMMENDATIONS

Although a practical procedure for the economic evaluation of industrial buildings is feasible, it has its limitations, as noted in the Conclusions. However, these limitations can be largely overcome by further investigation and action upon the following recommendations:

1. A procedure should be developed for periodic evaluation of the cost relationships between materials and labor for construction and maintenance.

2. The above procedure should incorporate a review of current policies of taxation, interest, and building codes as they affect the industrial building industry.

3. Through cooperation with various representative industries operating in a representative cross-section of building types of various materials a reporting system could be developed for summarizing the cost of industrial building maintenance, housekeeping and other costs. This would provide reliable data on this subject for use in a refined design evaluation procedure.

APPENDIX

AN INDUSTRIAL BUILDING SURVEY

Date: 9/13/68

COMPANY NAME Freeport Kaolin Company, Gordon, Georgia

INTERVIEWED Mr. Jim Gann POSITION Proj.Engr.

PRODUCT OR
SERVICE Industrial Pigments - Kaolin

CHARACTERISTICS OF
INTERNAL ENVIRONMENT Bagging Buildings - Dusty, dry, neutral

BUILDING CHARACTERISTICS

FRAME (CONSTRUCTION TYPE) Rigid (Steel) Frame

(MATERIAL)

FLOORS (MATERIAL) Concrete

WALLS (CONSTRUCTION TYPE) Corrugated Metal

(MATERIAL) Enameled Steel

ROOF (TYPE) Corrugated Metal

(MATERIAL) Enameled Steel

CONSTRUCTION COST/SQUARE FOOT $4.25

MAINTENANCE COST/SQUARE FOOT $0.35

IS MAINTENANCE COST INCREASING WITH AGE? yes

TYPE OF MAINTENANCE PREVALENT Housekeeping, replacement of damaged panels.

AN INDUSTRIAL BUILDING SURVEY

Date: 9/10/68

COMPANY NAME Huber Clays, Macon, Georgia

INTERVIEWED Mr. Tom McAllister POSITION Chief Engr.

PRODUCT OR SERVICE Industrial Pigments - Kaolin

CHARACTERISTICS OF
INTERNAL ENVIRONMENT Filter buildings - humid, corrosive, hot

BUILDING CHARACTERISTICS

FRAME (CONSTRUCTION TYPE) Laminated Wood

FLOORS (MATERIAL) Concrete, broom finish, metal platforms

WALLS (CONSTRUCTION TYPE) Brick and trnslucent panels

ROOF (TYPE) Corrugated Steel

(MATERIAL) Stainless steel - 316, 22 Ga.

CONSTRUCTION COST/SQUARE FOOT \$6.60

MAINTENANCE COST/SQUARE FOOT \$0.65

IS MAINTENANCE COST INCREASING WITH AGE? ____________

TYPE OF MAINTENANCE PREVALENT Housekeeping, repainting steel platforms, recoating laminated beams - 2 years

AN INDUSTRIAL BUILDING SURVEY

Date: 7/17/68

COMPANY NAME Mayo Chemical Company, Atlanta, Georgia

INTERVIEWED Mr. Jim Hall / Mr. Bill Macke POSITION Engineer / Vice Pres.

PRODUCT OR SERVICE Bleach - NaOCl

CHARACTERISTICS OF INTERNAL ENVIRONMENT Humid, corrosive, poor ventilation

BUILDING CHARACTERISTICS

FRAME (CONSTRUCTION TYPE) Steel truss - for new buildings, considering wood frame

FLOORS (MATERIAL) Concrete - glaze finish - need broom finish, seamless slab, w/moist. barrier

WALLS (CONSTRUCTION TYPE) Corrugated Asbestos - Good service

ROOF (TYPE) Corrugated asbestos

CONSTRUCTION COST/SQUARE FOOT $3.75

MAINTENANCE COST/SQUARE FOOT $0.75-$0.80

IS MAINTENANCE COST INCREASING WITH AGE? Yes

TYPE OF MAINTENANCE PREVALENT Repairs and repainting trusses, replacement of damaged asbestos - building life 10-12 years.

AN INDUSTRIAL BUILDING SURVEY

Date: 7/31/68

COMPANY NAME The Coca-Cola Company, Atlanta, Georgia

INTERVIEWED Mr. John Shaw POSITION Chief Arch.

PRODUCT OR SERVICE Soft Drinks - Carbonated

CHARACTERISTICS OF
INTERNAL ENVIRONMENT Up to 100% humidity, temp. less 80°F

Image to customers - wholesomeness, cleanliness

quality, efficiency.

BUILDING CHARACTERISTICS

FRAME (CONSTRUCTION TYPE) West & Northwest - laminated wood beams

other locations - concrete & steel

FLOORS (MATERIAL) Epoxy & Quarry Tile, Terrazzo - Sealed seams,

resist carbonic & phosphoric acid. Warehouse -

"Chem-Comp" - large pours (up to 10,000#) seamless.

WALLS (CONSTRUCTION TYPE) Brick or insulated metal of reinforced

pre-cast concrete, 6" tk, 20 ft high

ROOF (TYPE) Open web joist, built-up roofs

CONSTRUCTION COST/SQUARE FOOT $9.50-$14.50

MAINTENANCE COST/SQUARE FOOT $1.50-$1.75

IS MAINTENANCE COST INCREASING WITH AGE? No

TYPE OF MAINTENANCE PREVALENT Housekeeping - Big image problem

Building life - 40 years.

AN INDUSTRIAL BUILDING SURVEY

Date: 7/24/68

COMPANY NAME Fulton Industries, Atlanta, Georgia

INTERVIEWED Mr. Watson POSITION Maint. Superin.

PRODUCT OR SERVICE Textiles - Cotton, synthetic, rayon, bolt & bale

CHARACTERISTICS OF INTERNAL ENVIRONMENT Weave rooms - wood beam & column, heat 80^{o}F, 80 - 90% humidity

Bleach room - 85% humidity, corrosive, heat

BUILDING CHARACTERISTICS

FRAME (CONSTRUCTION TYPE) Flat roof, open web joist, wood

(MATERIAL) Wood

FLOORS (MATERIAL) Wood - high maint. No static electricity

Concrete (after 1945)

WALLS (CONSTRUCTION TYPE) Masonry - Precast concrete & bricks

(MATERIAL) Concrete & Bricks

ROOF (TYPE) Built-up

(MATERIAL) Wooden & concrete decks

CONSTRUCTION COST/SQUARE FOOT $4.50-$5.50

MAINTENANCE COST/SQUARE FOOT /Yr. $.50-$.75

IS MAINTENANCE COST INCREASING WITH AGE? No

TYPE OF MAINTENANCE PREVALENT Windows - Breakage, wood frames rot, steel frames rust. Roof leaks, floors-resanding & sealing - 6 months.

AN INDUSTRIAL BUILDING SURVEY

Date: 7/23/68

COMPANY NAME Southern Iron & Equipment Company, Atlanta, Ga.

INTERVIEWED Mr. Penson POSITION

PRODUCT OR SERVICE Rebuilding railroad cars

CHARACTERISTICS OF
INTERNAL ENVIRONMENT Neutral

BUILDING CHARACTERISTICS

FRAME (CONSTRUCTION TYPE) 40 ft steel truss

FLOORS (MATERIAL) wood, concrete

WALLS (CONSTRUCTION TYPE) Corrugated metal, glass windows, w/steel frames

ROOF (TYPE) Corrugated metal w/skylights

CONSTRUCTION COST/SQUARE FOOT $3.75

MAINTENANCE COST/SQUARE FOOT $.35-$.40

IS MAINTENANCE COST INCREASING WITH AGE? No

TYPE OF MAINTENANCE PREVALENT Truss painted 3-4 years, replacement of broken glass, damaged wall members

AN INDUSTRIAL BUILDING SURVEY

Date: 7/

COMPANY NAME Industrial Piping Supply, Inc., Atlanta, Ga.

INTERVIEWED Mr. Lowell Fambrough POSITION Manager

PRODUCT OR SERVICE Warehouse - Sales & Distribution of Piping Supplies

CHARACTERISTICS OF
INTERNAL ENVIRONMENT Neutral

BUILDING CHARACTERISTICS

FRAME (CONSTRUCTION TYPE) Steel Truss - suspended crane

FLOORS (MATERIAL) Warehouse - Concrete & Gravel

WALLS (CONSTRUCTION TYPE) Brick - 15 ft, corrugated metal 8 ft.

ROOF (TYPE) Corrugated metal w/translucent panels

CONSTRUCTION COST/SQUARE FOOT $5.50

MAINTENANCE COST/SQUARE FOOT $.25-$.30

IS MAINTENANCE COST INCREASING WITH AGE? No

TYPE OF MAINTENANCE PREVALENT Repair to floor, replace gravel & damaged wall panels, painting- 5-6 yrs.

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